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MANUAL FOR THE DESIGN OF HOT BITUMINOUS MIXES

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MANUAL FOR THE DESIGN OF HOT BITUMINOUS MIXES

CHAPTER 1

OVERVIEW OF BITUMINOUS MIX DESIGN

Indian Roads Congress has published several codes and Guidelines on bituminous construction on roads and highways. The design of these hot mix hot laid mixes is a complicated matter where a delicate balance has to be struck with regard to the mix ingredients (the aggregates and binder) to produce a strong and durable mix. This chapter is in the form of a backgrounder for mix design aimed at the uninitiated readers without specifying any target values of the properties of the ingredients or the mix to be achieved in the design (which are subject matter of the subsequent chapters of this Manual). The experts may skip this chapter without losing much, but the new entrants may gain some insight into the field of Mix Design.

Section 1.1 of this Chapter attempts to describe the theoretical aspects of the mix ingredients as well as the mix under the actual traffic loading and climatic conditions. Based on these discussions the outline objectives of the Mix Design have been discussed in Section 1.2. The current approaches to Mix design have been discussed in Section 1.3. The knowledge and resource gaps and the road map for developing a sophisticated Mix Design procedures are outlined in Section 1.4. The task of preparation of this document was taken up by the Flexible Pavement, Airfields and Runways Committee (H-2) of IRC. A subgroup consisting of Dr. Sunil Bose (Chairman) and Prof. (Dr.) Sridhar Raju were constituted to prepare the draft. The draft prepared by the subgroup was deliberated in a series of meetings and was finalized in H-2 meeting held on 21.05.2022.

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The revised draft document was placed before the Highways Specifications and Standards Committee (HSS) in its meeting held on 04.06.2022. The HSS Committee approved this document subject to suitably incorporating written and verbal comments received and also recommended it for placing before the meetings of Executive Committee (EC) and Council. The EC in its meeting held on 16.06.2022 approved the draft document for placing before the Council. The 222nd Mid-Term Council in its meeting held on 17th – 18th June, 2022 at Shillong (Meghalaya) considered and approved the draft "Manual for the Design of Hot Bituminous Mixes" for printing.

1.1 Theoretical Aspects of Mix Design

1.1.1 *Mix Ingredients*

a. The main ingredients of a bituminous mix are mineral aggregates, bitumen binder, and a small amount of inert filler (particle size finer than 75 micron). The aggregates in the mix provide aggregate structure by providing inter-granular friction. The bitumen in the mix provides cohesion to the mix by binding the aggregate particles at points of contact. Fillers provide stiffness to the mix by further increasing the cohesion.

b. *Aggregates:* There are two main requirements of aggregates (a) its quality in terms its own strength (represented by its impact vale, abrasion value, shape of its particles, porosity, soundness) and (b) its gradation, which indicates how closely packed the aggregate particles are to provide the aggregate skeleton or aggregate structure (dense grading, open grading or gap grading).

Aggregate structure in a dense mix is densely packed, because of which air voids are the minimum. This grading closely follows the maximum density curve (Fuller's curve) the equation of which is as follows:

$$P_i = (d_i/D)^{0.45}$$

Where, P_i=Per cent passing by weight through i^{th} sieve, d_i = sieve size of the i^{th} sieve, and D= Nominal Maximum Aggregate size (NMAS), which is the size through which at least 90 per cent of aggregates pass (or not more than 10 per cent are retained)

In gap graded aggregates, the middle size fractions are missing, as a result the air voids in the aggregates are relatively more than dense grading.

In open graded aggregates, a large per cent of the coarse aggregates are within a narrow range of aggregate sizes with small amount of finer fractions. The air voids are very high. These are very permeable grading.

c. *Bitumen:* Bitumen in the dense graded mix acts (a) to coat the aggregate particles so that they remain stuck to one another and the aggregate structure (and hence the shear strength) remains intact (b) to give cohesion to the mix which contributes to its shear strength, (c) to fill the voids in the aggregates and make the mix impervious. Since the voids in aggregates are relatively low in the dense graded mix, the quantity of bitumen required is also less. The disadvantage of less bitumen is that the thickness of the bitumen film coating the aggregate particles is also less and, therefore, the mix is more susceptible to oxidation.

In gap graded and open graded mixes the voids are more and, therefore, the bitumen quantity will be relatively more. The strength in these mixes comes from the bitumen coated fine aggregate mortar in which the coarser particles are supposed to be embedded. The strength of the mix is thus the strength of the mortar. Because of high bitumen quantity, these mixes are less susceptible to oxidation. Mixes with these grading drain quickly through the space between loosely packed coarse aggregates and the impervious mortar prevents water to entre lower layers.

1.1.2 *Strength and Durability*

The mix when laid and compacted in a pavement layer needs to have strength to withstand the traffic load and durable under the prevailing environmental conditions (temperature, rainfall, exposure to ultra violet radiation from sun). The vertical load imposed by wheels cause tensile stresses at the bottom of the layer as the layer material is free to move at the layer interface, or in other words some tensile strain would occur. At the top of the layer, the pressure in the pneumatic tyre of the wheel would push the layer material sideways, causing shear stresses to develop. Thus, the pavement layer develops both tensile as well as shear stresses when a load passes over it. The mix material should have sufficient strength to resist these stresses.

1.1.3 *Tensile Strength*

This comes from the elastic modulus (called Resilient Modulus in the context of pavements) of the mix in the layer. Bituminous mixes are known to behave in a resilient (or elastic) manner under certain conditions (such as within a temperature range) when the deformation in the pavement layer (or strain) by application of the wheel load (or stress) is recovered after the load is removed, as in the equation below.

Stress/Strain= Resilient Modulus (M_R)

1.1.4 *Shear Strength*

This comes from the inter-granular friction generated by the aggregates in the mix (the frictional component) and the cohesion provided to the mix by the viscous bituminous binder (cohesion part) when the wheel load (vertical or normal stresses) passes over a point in the pavement, as in the typical shear stress equation 1.1

$$\sqsubset = C + \sigma \tan \varphi \qquad \textit{Eq 1.1}$$

Where $\sqsubset$ = shear stress, σ = normal stress, and φ= angle of internal friction

1.1.5 *Visco-Elastic Nature of Bitumen Binder*

a. Bitumen is a visco-elastic material, i.e., it behaves as an elastic solid as well as a viscous fluid. Bitumen is more an elastic solid than a viscous fluid at low temperature, its viscosity being very high. As the temperature rises, it becomes less an elastic solid and more a viscous fluid, its viscosity progressively decreasing.

b. Bitumen is a non-Newtonian fluid in the temperature range expected during the life of the pavement. (It becomes a Newtonian fluid only at temperatures above 135°C) The characteristics of a non-Newtonian fluid is that its viscosity also changes with rate of shear. At slower rate of applied shear stresses (e.g., at slower traffic speed or practically stand still traffic) its viscosity is lower than that at high rate of shear (e.g., high speed traffic).

c. The discussion in paras 'a' and 'b' would lead to the qualitative conclusions with regard to the Visco-Elastic properties of bitumen binder as given in **Table 1.1**.

Table 1.1 Visco-Elastic Properties of Bitumen Binder

Field conditions	Tensile strength	Shear strength	Reasons
Low temperature	High (because M_R high)	High (because C high)	More elastic solid and less high viscosity fluid
High temperature	Low (because M_R low)	Low (because C low)	Less elastic solid and more low viscosity fluid
Slow traffic	No effect	Low (because Viscosity low)	Low rate of applied shear and hence reduced viscosity
Fast traffic	No effect	High (because Viscosity high)	High rate of applied shear hence more increased viscosity

1.1.6 *Ageing of Bitumen*

a. Bitumen starts ageing very fast, even within hours of being unpacked or taken out of bitumen tanks. Ageing is associated with oxidation of bitumen when exposed to atmosphere or high temperature. An aged bitumen becomes hard and brittle. Typically, the top bituminous layer in the pavement is more prone to ageing as it remains exposed to atmosphere and sun light, especially the ultraviolet radiation in sunlight. After ageing the bitumen, the top surface of the bituminous layer cracks, which progressively increases as the bitumen through cracks gets further exposed. This initiates top-down cracking in bituminous mixes.

b. The phenomenon of ageing has been explained by bitumen chemistry. Bitumen, a hydrocarbon and residue of the process of refining of crude oil, is a colloidal mixture having four components: Saturates, Aromatic oils, Resins and Asphaltene (acronym SARA). The quickest to be oxidized are the highly volatile Aromatic Oils, followed by Saturates, which constitute the bulk of the bitumen. Resins, which are responsible for the cohesive properties, encapsulate the Asphaltene, an amorphous solid, which gives elastic property to bitumen. Resins are the last to oxidize. As the volatiles and saturates get oxidized, the bitumen becomes hard and brittle. Oxidation is accelerated at high temperature (pavement temperature as well as plant temperature). Overheating of bitumen in the Mixing Plant causes the bitumen to be oxidized and lose its properties.

1.1.7 *Performance Parameters*

Performance of a mix is judged by three main performance parameters, viz., (a) fatigue cracking, (b) Rutting, and (c) low temperature cracking. These are also the Serviceability parameters because a pavement layer cracked or rutted beyond a limit (e.g., cracked area beyond a certain percentage, rut higher than a certain specified depth and spacing of low temperature cracking less than a specified minimum) becomes unserviceable and would need rehabilitation. A fourth performance parameter is moisture susceptibility (stripping and raveling) for preventive measures are taken without specifying any performance threshold.

a. Fatigue cracking is the result of tensile failure. Strain in the pavement bottom is both elastic as well as plastic. With every repetition of wheel load some plastic strain gets accumulated reducing the scope of elastic strain and hence the tensile strength. This phenomenon starts initially with micro cracks, which eventually turns into wider cracks, which, with continued repetition of wheel loads reflect into the top of the layer and even in the overlying layer(s).

b. Rutting is the result of shear failure of the mix. The shear stresses caused by the lateral pressure of the pneumatic tyres of the wheels dilate the mix on either side of the wheel path, which goes on accumulating with every successive passage of load. As a result, the rut forms along the wheel path. As discussed above, shear resistance depends upon rate of shear. Slower shear rate as in slow traffic causes more rutting. Overloaded wheels also cause more rutting.

c. Low temperature cracking is also a tensile failure situation. When pavement temperature is low, it would tend to shrink, which causes tensile stresses to be mobilized by the pavement layer. Since bitumen at low temperature is hard and brittle (i.e., not ductile), the pavement layer cracks in the transverse direction. Closer the spacing of the cracks, more severe is the failure and less is the serviceability of the pavement.

d. Moisture damage is caused if the coating of aggregate surface by bitumen is weak (either in the initial mixing or by oxidation). Water breaks the weak bond between the aggregate and binder and replaces the bitumen on the aggregate surface causing stripping. Stripping leads to raveling and eventually disintegration of the mix.

1.2 Objectives of Mix Design

The ultimate objective of Mix design is to design a mix that has strength (tensile and shear) and durability under the given environmental conditions to resist fatigue cracking and rutting in the pavement design life (the number of cumulative standard axles). This can be achieved by

(a) ensuring the quality of mix ingredients,

(b) proportioning of the mix ingredients in the optimal manner, and

(c) supplementing the design by performance tests on the mix to predict its behaviour during its service life [such Superpave Shear Testing (SST) and Indirect Tensile Testing (IDT), in the Superpave design).

As regards (a), ensuring the quality of mix ingredients itself can provide a high-performance mix, particularly if the binder selection is done based on dynamic shear tests and Thin Film Oven Test on likely pavement temperatures and the threshold values (as specified in Superpave) of $G^*/\sin\delta$ are crossed.

As regards (b), it is simply the Volumetric Design which is the starting point of all mix design (even in Superpave design). In volumetric design (e.g., Marshall Method) controlling the Air Voids in the Mix is of prime importance. The compacted mix in the field undergoes secondary compaction due to traffic and there will be reduction in air voids with passage of time. Air voids in the field should not reduce to an extent that with expansion of bitumen due to temperature rise all the voids are filled and the aggregates are in a 'floating matrix' losing all strength and stability. Usually, 4 per cent air voids are targeted in laboratory so that after secondary compaction these should not reduce below 2.5 per cent. The mix passes the muster if the test specimens of the mix meet the specified stability and flow values. What should be the compactive effort and manner of compaction while preparing the test specimen is an unresolved issue (whether compaction by impact as in Marshall, by kneading as in Hveem or Gyration as in Superpave) as there are claims and counter claims with regard to the compaction in laboratory simulating the field compaction.

As regards (c), this practice has not so far been followed in the country nor it is considered useful unless a performance model (as in Superpave) exists to predict the performance of the mixes.

1.3 Approaches to Design of Bituminous Mixes

There are two approaches to the Mix design, viz., Volumetric Design (the best example of which is the Marshall Method of Design) and Performance-based Design (the best example of which is the Superpave Design).

1.3.1 *Volumetric Design Procedure*

Stated in simple terms, the Volumetric design procedure assumes that a packed mineral aggregate volume has a certain per cent of voids (Voids in Mineral aggregates or VMA), part of which is filled with bitumen (or VFB) and the other part occupied by Air (Volume of Air Voids, V_a). The purpose of the mix design is to find out the optimum binder content (VFB) that gives the acceptable stability and flow values at a specified per cent of air voids. The air voids are the critical design parameter because these are the proxies for field compaction level. A high air void would result in relatively low compaction leaving a scope for secondary compaction under traffic and increased chances of rutting of the bituminous layer. Low air voids represent expectation of

high field compaction, which at times is difficult to achieve, and even if somehow achieved, all the air voids may get filled when bitumen expands in volume with rise in pavement temperature, leaving zero air void and making the mix unstable.

a. The simplistic volumetric approach has already been refined by taking into account the fact that the aggregates do have surface pores in which a part of the bitumen gets absorbed and is wasted. Therefore, VFB has to be adjusted for this wasted bitumen and only effective binder content (V_{be}) has to be considered in the design.

b. The volumetric parameters have to be changed to gravimetric because bitumen volume is always subject to change with temperature while the mass remains constant irrespective of temperature, and also because bitumen quantity in the design is specified in terms of weight of the total mix. This requires calculation of density of the mix by ignoring the volume of air voids (G_{mm}) and the density of the bitumen at the test temperature.

c. An outline of the desirable volumetric design procedure to meet the objectives of mix design is presented below:

   i. Select the quality of aggregates after tests (abrasion, impact, flakiness/ elongation, water absorption, soundness)

   ii. Select the bitumen that can work in the field temperature conditions after tests (viscosity, dynamic shear, ageing)

   iii. Prepare the trial blends of aggregate fractions corresponding to the required grading as per specifications (DBM, BC)

   iv. Choose trial dozes of bitumen

   v. Prepare the test specimens by mixing the trial aggregate blends and bitumen dozes by mixing in the laboratory and compacting as per accepted procedure

   vi. Test the specimen for stability and flow (Marshall) and calculate the other mix parameters (Air voids, Voids in Mineral Aggregates, Voids filled with Bitumen) and prepare a plot of each of these parameters against the binder content.

   vii. Decide the target Air Voids (usually 4 per cent) and determine the binder content corresponding to the target Air Voids

   viii. Determine from the plots whether the stability and flow are optimally met with the binder content as determined in (vii)

   ix. The items (v) to (viii) should be repeated for plant produced mix to validate the production process and (vi) to (viii) on cores taken from the field compacted mix to validate the field compaction process.

1.3.2 *Performance-based Approach*

In performance-based approach, the design process attempts to create the field conditions in the laboratory through various means, such as (i) simulating the traffic load in preparing test

specimens, (ii) selecting quality of aggregates and their grading by the position of the mix in the pavement (e.g., surface course or base course), (iii) selecting binder by conducting tests (e.g. Rolling Thin Film Oven or RTFO test for ageing of bitumen), Dynamic Shear Rheometer or DSR Test for determining the visco-elastic properties to demonstrate that it can work under the field loading conditions and pavement temperature range, (iv) conducting special tests in the laboratory (e.g., shear and/or tensile test) to assess the likely failure of the mix under field conditions.

a. Superpave, an acronym for 'Superior Performing Asphalt Pavements' is the outcome of the Strategic Highway Research Program (SHRP) undertaken between 1987 and 1993 by the US Department of Transport, Federal Highway Administration (USDoT, FHWA). This is currently the state-of-the art in performance-based design.

b. Superpave design is a three-level process starting with the volumetric design at Level I. There is no further requirement of testing if the traffic is low (less than 1 MSA). Level II design, which is applicable for traffic in the range of 1 to 10 MSA, involves Level I design to be input to a Performance Prediction Model, which predicts 'go' or 'no go' option with the design. In the case of 'no go' option in Level II design or traffic level in excess of 10 MSA, Level III design is done. It requires Superpave Performance testing to be done for Level II and Level III design, which are (a) a set of Superpave Shear tests (SST) for predicting rutting resistance and (b) Indirect Tensile testing (IDT) for predicting fatigue cracking.

c. There are other protocols in Superpave Design, relating to quality of mix ingredients, the aggregates and binders. Two types of aggregate properties, viz, the 'Consensus Properties' and 'Source Properties' are specified in Superpave. Consensus Properties are those, which are required to be mandatorily followed for designing the Hot Mix Asphalt (HMA) and these include angularity of coarse aggregates (in terms of fractured faces) angularity of fine aggregate (in terms of voids in loose sand), flatness (flakiness) and elongation, and clay content (in terms of percentages). The Source Properties include toughness (in terms of LA abrasion), soundness (in terms of loss in weight when dipped in Sodium Sulphate and Magnesium Sulphate solutions) and deleterious matter. Aggregate grading is a Consensus property, where control points of grading are close to the maximum density except for the 'critical zone' (size fractions 2.36 mm to 75 micron) where the per cent passing should be less than that in the maximum density line to reduce the fine sand fraction in the mix, which is known to give a tender mix.

d. Binder in Superpave is the 'Performance Grade' (or PG grade) binder, specifying the maximum temperature and the range of temperature up to and within which the binder would be considered effective (e.g., if the binder grade is $PG_{64\text{-}22}$, the binder would be suitable in the temperature range of 42 to 64°C). Binder selection is based on the pavement temperature likely to be encountered in the field, which is determined by a model that uses 7-day maximum air temperature and the geographic position (latitude and longitude) as the inputs. In addition

to binder grade selection there are other tests required to be done on binder (both on original binder and binder aged in Thin Film Oven or Pressure Ageing Vessel). The most important among them are the Viscosity of binder at test temperature (including elevated temperature) in rotational viscometer, the value G*/sinδ (where G* is the Complex Modulus and δ is the Phase angle in Dynamic Shear Rheometer test), Creep Stiffness, and Direct Tension.

1.4 The Way Forward

A Mix design procedure like Superpave does not seem to be round the corner for application in India as it requires sophisticated performance testing procedures and equipment as well as a performance prediction model using test results as the inputs to predict performance in the field. Until these developments take place, the current volumetric design procedures would continue to be followed. These procedures could, however, be further refined by following the Superpave protocols as regards quality of mix ingredients, important among which are listed below:

a. Aggregate grading, a 'Consensus Property' in Superpave Protocol, requires controlling the fine sand fraction (2.36 mm to 75 micron) below the maximum density line to check tenderness of the mix (or shoving of the mix in front of the roller). This needs to be given a serious thought in reviewing our aggregate grading specification.

b. Binder selection in our system is based on 'Viscosity Grading' (e.g. VG 30, VG 40, etc.) as opposed to 'Performance Grading' (e.g., PG 64-XX, PG 70-XX) in the Superpave design. Our test procedures require the Viscosity to be tested at 60°C, which more often than not are less than the maximum pavement temperature and hence not representative of the pavement temperature.To overcome this handicap, the Viscosity test should be supplemented by Dynamic Shear Rheometer (DSR) test and the G*/sinδ values should be obtained at the pavement temperatures. The acceptable values corresponding to a temperature should be considered to be adopted as per Superpave recommendations.

c. Pavement temperatures are not directly measured but there is a global model for predicting the pavement temperature based on by 7-day maximum air temperature and geographical position of a place (latitude and longitude). This model has been referred to in IRC:37-2018 as well.

d. There are other tests which can reveal the ageing behavior of the pavement, such as Rolling Thin Film Oven Test (RTFOT) at mixing temperature and Pressure Ageing Vessel (PAV) for bitumen ageing at pavement temperatures. These tests also should be part of binder selection process in our overall mix design procedure.

e. Compaction method (impact, kneading, gyration) and Compactive effort (number of blows or gyration) to be applied in preparation of test specimens require further consideration. Similarly, the specifications for performance parameters of the Mix (Stability and Flow) corresponding to the method and the effort would need to set/reset.

f. Indirect tensile testing is already a part of our pavement design procedure (ref IRC:37-2018) and Shear Tests are not likely to come any time soon. In the absence of the latter, our mix design procedure should rely more on the binder property tests as indicated above and commensurate laboratory facilities need to be created in the country.

CHAPTER 2

DENSE HOT BITUMINOUS MIX DESIGN

This manual proposes a methodology for the design of dense hot bituminous mixes suitable for Indian conditions. This also takes into account a number of practical considerations. In India, generally the Marshall method of mix design is used for preparing the dense bituminous mixes with low permeability, good resistance against rutting and cracking. The methodology and procedures outlined in this manual for the design of dense bituminous mixes are obtained from different sources, and compiled considering the best practices and as per international standards.

2.1 Requirements for Design of Bituminous Mixes

The main aim of bituminous mix design is to select and proportion the aggregate and bitumen, including the filler, to obtain a strong, durable and an economical mix. A properly designed mix will be durable and resist overloading throughout its service life. The mix should be designed to strike a balance between moisture damage, rutting, and cracking. If the bituminous mix is used as a surface layer, the mix should meet the functional requirements such as ride comfort, and moisture resistance.

2.2 Design Approach

For a durable mix, the existing guidelines have a series of tests to assess the performance characteristics of dense bituminous mixes. A few of the routine tests have limited field performance correlation (e.g. Marshall stability and flow). In this manual, moisture damage test for low traffic roads (<10 msa), moisture damage, rutting, and fatigue tests for medium traffic (10-20 msa), high traffic (20-50 msa), and very high traffic (>50 msa) are considered. The performance tests carried out on the bituminous mixes are moisture resistance, rutting and cracking. To assess the moisture resistance, the indirect tensile strength ratio (AASHTO T283) shall be performed. The Hamburg Wheel Tracking Tests (HWTT) shall be carried out as per AASHTO T324 to assess rutting criteria. The Indirect tensile fatigue testing (ITFT) as per ASTM D7369-20, for assessing the fatigue behaviour.

2.3 Structure of the Manual

This manual is intended to comprehensively cover the design of all the bituminous mix types that are currently used in India.

- Chapter 1: Introduction
- Chapter 2: Mix Type Selection
- Chapter 3: Selection of Binder

- Chapter 4: Selection of Aggregate
- Chapter 5: Bituminous Mix Design as per Marshall Method
- Chapter 6: Factors Influencing Performance of Bituminous Mixes
- Chapter 7: Mixture Design using Reclaimed Asphalt Pavement (RAP)
- Chapter 8: Superpave Mix Design

CHAPTER 3

MIX TYPE SELECTION

Mix type selection is based on the Nominal Maximum Aggregate Size (NMAS). NMAS is the largest specified sieve size upon which any of the aggregate material is retained.

3.1 Dense Graded Bituminous Mixes

In dense graded bituminous mixes,all primary aggregates are closely packed and graded continuously. The reason behind their attribute of strength gain is inter-particle surface friction. The example of dense-graded bituminous mixes are Bituminous Concrete (BC), and Dense Bituminous Macadam (DBM).

3.2 Factors that influence Bituminous Mixes Type Selection

3.2.1 *Traffic*

The traffic classification to select a bituminous mix is given in **Table 3.1.**

Table 3.1 Traffic Category for Mix Design

Design Traffic in Million Standard Axles (msa)	Traffic Level
<10	Low traffic
≥10<20	Medium traffic
≥20<50	High traffic
>50	Very high traffic

3.2.2 *Traffic Speed*

The speed of heavy trucks can significantly influence the performance of a bituminous mix. A slow-moving vehicle have a negative impact on rutting potential of the bituminous mixes. If the vehicle is moving at low speeds at higher pavement temperature, the loading rate causes deformation of the mix, increasing the likelihood of rutting (e.g., rutting along the wheel paths). Therefore, the NMAS, and the binder type has to be selected based on the pavement temperature and traffic level.

3.2.3 *Rainfall*

Mixtures laid in high-rainfall coastal areas or North-eastern part of India with a considerable number of wet days have a higher risk of stripping. Therefore, the bituminous mixesmay require an antistripping additive.Therefore, the rainfall may influence the aggregate, filler, and binder types.

CHAPTER 4

BITUMINOUS BINDER

4.1 Bitumen Tests for Viscosity Grade Bitumen

Bitumen is presently graded based on the viscosity value at 60°C. The tests performed on viscosity grade bitumen are dynamic viscosity (using the capillary U tube viscometer), softening point (Ring & Ball test), ductility, solubility, specific gravity, flash point and ageing as per IS 1201 (1978) to IS 1220 (1978).

4.2 Viscosity Grade Bitumen

This manual explains the viscosity grade specification, methodology, and related testing. The current specifications for the commonly used viscosity grade binders in the design of bituminous mixes is given in **Table 4.1** (IS:73-2019). However, the polymer modified binders are tested in accordance with IS:15462-2019.

Table 4.1 Requirement for Paving Bitumen (IS: 73-2013)

Characteristics	Paving Grades				Method of Test Ref to
	VG10	VG20	VG30	VG40	
Penetration at 25 °C, 100 g, 5 s, 0.1 mm, Min	80	60	45	35	IS 1203
Absolute viscosity at 60 °C, Poises	800-1200	1600-2400	2400-3600	3600-4800	IS 1206 (Part 2)
Kinematic viscosity at 135 °C, cSt, Min	250	300	350	400	IS 1206 (Part 3)
Flash Point (Cleveland open cup), °C, Min	220	220	220	220	IS 1448 [P:69]
Solubility in trichloroethylene, percent, Min	99.0	99.0	99.0	99.0	IS 1216
Softening point (R&B), °C, Min	40	45	47	50	IS 1205
Tests on residue from rolling thin film oven test:					
a) Viscosity ratio at 60 °C, Max	4	4	4	4	IS 1206 (Part 2)
b) Ductility at 25 °C, cm, Min	75	50	40	25	IS 1208

4.2.1 *Temperature*

The maximum pavement temperature will help in the selection of binder type. The maximum pavement temperatures prevailing in different parts of the country is given in **Table 4.2**, using the equation given in A.5.5 of IRC:37-2018.

Table 4.2 Pavement Temperatures in Indian Cities

Place Name (INDIA)	State	Latitude	Air Temp (°C)	Pavement Temp (°C)
Delhi	Delhi	28.61	45	66.87
Gurdaspur	Punjab	32.04	45	66.40
Lucknow	UP	26.85	45	67.07
Roorkee	Uttarakhand	29.85	35	57.17
Sirohi	Rajasthan	24.88	47	69.15
Jalpaiguri	West Bengal	26.54	34	56.60
Munger	Bihar	25.38	47	69.11
Guwahati	Assam	26.18	45	67.13
Bhusawal	Maharashtra	21.05	45	67.44
Mumbai	Maharashtra	19.16	35	57.93
Surajpur	Chhattisgarh	23.22	46	68.30
Suryapet	Telangana	17.14	45	67.46
Vizianagaram	AP	18.11	48	70.34
Himmatnagar	Gujarat	23.60	42	64.46
Harihar	Karnataka	14.53	46	68.34
Kollam	Kerala	8.89	35	57.38
Tirumangalam	Tamil Nadu	9.82	40	62.26
Udupi	Karnataka	13.34	37	59.68

4.3 Modified Bitumen

To overcome the short comings in viscosity grade bitumen, the modified bitumen can be used as per IS:15462-2019, and IS:17079-2019. The polymer modifier binder requirements as per the Indian standards are given in **Table 4.3.** Similarly, for crumb rubber modified bitumen, table from IS:17079-2019, may be referred.

Table 4.3 Requirements for Polymer Modified Binders

Characteristics	Paving Grades					Method of Test Ref to
	PMB 64-10	PMB 70-10	PMB 76-10	PMB 82-10	PMB 76-22	
Softening point (R&B), °C, Min	60	65	70	80	75	IS 1205
Elastic Recovery at 15 °C, %, Min	70	70	70	80	75	ASTM D113
Viscosity at 150 °C, Pa.s, Min	1.2	1.2	1.2	1.6	1.5	ASTM D 4402
G*/sin δ as Min 1.0 kPa	64	70	76	82	76	ASTM D7175
Phase Separation, °C, Max	3	3	3	3	3	ASTM D7173

4.3.1 *Rotational Viscometer*

The viscosity of binders at high temperatures is determined using a rotational viscometer in accordance with ASTM D4402-06. The viscometer can be used to create temperature-viscosity charts that can be used for determining the mixing and compaction temperatures for the preparation of bituminous mixes.

4.3.2 *Dynamic Shear Rheometer (DSR)*

In accordance with ASTM D7175, the dynamic shear rheometer is used to determine the rheological properties of the binder at intermediate to high test temperatures. The complex shear modulus (G*) and phase angle (δ) are the parameters used to characterise the binder behaviour, where G* denotes the binder resistance to deformation, and δ denotes, the elastic and viscous nature. The Multiple Stress Creep Recovery(MSCR) studies as per AASHTO T 350 can be used to determine the binder's rutting performance. The Linear Amplitude test, as specified in AASHTO TP 101-14, can be used to estimate damage tolerance, which reflects the fatigue performance of the bitumen.

CHAPTER 5

AGGREGATES FOR BITUMINOUS MIXES

5.1 Introduction

Aggregate used in the design of bituminous mix, is in the range of 93 to 95% by the weight of mix. Aggregate is made up of hard materials that are obtained after crushing the solid rock or boulders.

For the design of bituminous mixes, the aggregate is classified coarse, fine, and filler. The coarse aggregate is the material retained on 4.75 mm sieve, fine aggregate is the material passing 4.75 mm, and retained on 75 µm sieve, and the filler is the material passing 75 µm sieve. The grading requirements for mineral filler is given in **Table 5.1**, as per MoRT&H Specifications.

Table 5.1 Grading Requirements for Mineral Filler

IS Sieve (mm)	Cumulative percent passing by weight of total aggregate
0.60	100
0.30	95-100
0.075	85-100

5.2 Source of Aggregate

There are mainly three main sources of aggregates

5.2.1 *Processed Aggregate*

in order to be used, processed aggregates are quarried, crushed, and screened. For bituminous mix design, cubical and/or angular crushed aggregates are preferred. Flat, and elongated aggregates should be limited to 35% as per MoRT&H.

5.2.2 *Manufactured Aggregates*

Industrial by-products, such as industrial slag can be used as aggregate in the design of bituminous mixes.

5.2.3 *Slag Aggregates*

Steel slag as an aggregate that helps in conserving the natural resources. It is vital to condition steel slag before utilising it as an aggregate in a bituminous mix to prevent expansion. Steel slag for road construction should be stored for at least three months and kept wet at all times using water spraying. However, the ITSR as per AASHTO T283, must be performed.

5.2.4 *Reclaimed Asphalt Pavement (RAP)*

RAP is a waste material obtained after milling the severely distressed pavement. Follow IRC:120-2015 guidelines for sampling the RAP material. If a parallel drum is used, higher RAP content can be employed, but only after fractionation.

5.3 Fillers

Fillers are necessary for constructing dense, cohesive, long-lasting, and water-resistant bituminous mixes. Filler may be:

- Stone dust
- Cement
- Hydrated lime with minimum 80% Calcium Carbonate

The filler in a bituminous mix:

i. Acts as a binder extender, stiffening the mastic and enhancing the mix's stability.

ii. It can be used to alter grading and volumetric properties by acting as a void-filling substance.

iii. Some fillers, such as lime, are used to enhance the bonding between the binder and the aggregate.

Filler types, features, and test procedures for determining their attributes are summarised in **Table 5.2.**

Table 5.2 Types of Fillers

Type of filler/origin	Characteristics	Test method/Criteria
Hydrated lime (active filler)	• Improves adhesive between binder and aggregate thereby reducing the stripping. • Improves mix durability by retarding oxidative hardening of the binder. • Low bulk density and high surface area. • Relatively high cost. • Improves stiffness and • Ensures Compactability.	Grading (85-100 % passing 75 µm)

Portland Cement (active filler)	• Relatively high cost. • Improves stiffness and • Ensures Compactability. • It acts as an inert filler.	
Stone Dust	• Variable characteristics require control. • Some source types may affect mix durability. • Some types may lead to tender mixes sensitive to small variations in binder content, which may require reduction in stone dust content.	
Limestone dust	• Manufactures under controlled conditions and compiles with set gradating requirements. • More cost-effective then active filler. • High pH value reduces moisture susceptibility. • 80% of the material shall pass 0.075 mm IS Sieve	
Fly Ash	• Use of fly ash is not recommended in the design of dense bituminous mixes.	

Note: *The filler-bitumen ratio should be in the range of 0.8 to 1.0. Higher filler binder ratio stiffens the mix, and lower filler-binder ratio affects the strength parameter.*

5.4 Aggregate Grading

In aggregate grading, a sample of aggregate materials is sieved through a defined set of sieves, and the proportion of material passing each sieve by mass is calculated.

5.4.1 *Grading Requirements*

The general requirements and specifications for aggregates are

- Crushed rock is the most common coarse aggregate. Certain forms of crushed blast-furnace slag can also be used, as long as they meet the strength requirements and doesn't absorb additional water.
- Crusher sand, slag sand, or a combination of these can be used as fine aggregate.
- **Table 5.3** in line with the MoRT&H Specification, lists the aggregates properties and requirements for bituminous mix design.

Table 5.3 Physical Properties of Coarse Aggregates

Property	Test	Requirements	Test method
Cleanliness	Grain Size Analysis	Max. 5% passing 0.075 mm	IS: 2386 Part 1
Particle Shape	Flakiness and Elongation Index (combined)	Max. 35%	IS: 2386 Part 1
Strength	Loss Angles Abrasion Value or Aggregate Impact Value	Binder layer -Max. 30% Others- Max 35%	IS 2386- Part IV
		Surface layer - Max. 24%	IS 2386- Part IV
Polishing	Polishing Stone Value	Min. 55	IS 2386- Part IV
Durability	Soundness (Either Sodium or Magnesium Sulphate)- 5 cycles		
	Sodium Sulphate	Max. 12%	IS 2386- Part V
	Magnesium Sulphate	Max. 18%	IS 2386- Part V
Water Absorption	Water Absorption	Max. 2%	IS 2386- Part III
Stripping (%)	Coating and Stripping of Bitumen Aggregate Mixture	Min. Retained Coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength	Min 80%	AASHTO 283

5.5 Preparation and Selection of Aggregate Grading

The following are the steps and guidelines for obtaining the design grading:

i. At bituminous mix plants, take samples of raw aggregate materials from stockpiles. An aggregate fraction of a certain magnitude is normally present in each stockpile. A composite grading for the mix is generated using a minimum of three fractions.

ii. The aggregates should be dried in the oven for a minimum of 16 hours at around 105°C. By riffling/quartering, the size of the samples for sieve examination is reduced. Mix bags of matching aggregate sizes to ensure sample uniformity.

iii. Check if aggregates are sufficiently riffled using a wet sieve analysis test on randomly selected bags of samples. Calculate the apparent and bulk densities for each coarse and fine aggregate component.

iv. Determine the bulk density of the mineral fillers in accordance with IS 2346.

v. Determine the aggregate fraction's individual attributes. **Table 5.3** lists the test techniques and criteria that should be used.

vi. Combine the grading of distinct aggregate fractions into trial blends of a single grading using the fundamental approach in Equation 5.1. Excel or any commercially available software that performs aggregate blending through trial and error can be used to generate blends.

$$P = Aa+Bb+Cc+\cdots+Nn \qquad \textit{Eq. 5.1}$$

P = % of materials passing a given sieve for the combined aggregates A, B, C
A, B, C, …N = % of materials passing a given sieve for aggregates A, B, C, …N
a, b, c, …n = proportions (decimal fractions) of aggregates A, B, C, in the blend (a, b, c, …n= 1.00).

vii Make at least three trial aggregate blends, and in case the blended aggregate fails to meet the gradation criteria, the proportions of aggregate should be adjusted.

5.6 Surface Area Calculation

The surface area of blended aggregate is required to determine durability of the bituminous mix, at optimum binder content. The surface area factor as per Shell Bitumen Handbook (sixth edition) is given in **Table 5.4.** The surface area is larger for finer aggregate particles. Equation 5.2 is used for computing the aggregate particle's Surface Area (SA):

Table 5.4 Typical Surface Area Factors

Sieve Size (mm)	Surface Area Factor (m2/kg)
0.075	32.77
0.150	12.29
0.300	6.14
0.600	2.87
1.18	1.64
2.36	0.82
>4.75	0.41

BC 1 mid gradation as per MoRT&H Specifications is given in **Table 5.5**. An example showing the film thickness calculation for BC 1 mid gradation with a minimum bitumen content of 5.2% is given below. The surface area of total aggregate is calculated using equation 5.2, as per Shell Bitumen Hand Book (Sixth Revision).

Table 5.5 BC 1 (Mid Gradation) as per MoRT&H Specification

Sieve Size	Percent Passing (%)
26.5	100
19.0	95
13.2	69
9.5	62
4.75	45
2.36	36
1.18	27
0.600	21
0.300	15
0.150	9
0.075	5
Minimum binder content	5.2

$$Surface\ area = 0.41+0.41\times a+0.82\times b+1.64\times c+2.87\times d+6.14\times e+12.29\times f+32.77\times g \quad Eq\ 5.2$$

a – percent passing 4.75 mm

b – percent passing 2.36 mm

c – percent passing 1.18 mm

d – percent passing 600 µm

e – percent passing 300 µm

f – percent passing 150 µm

g – percent passing 75 µm

$$Surface\ area = 0.41+0.41\times 0.45+0.82\times 0.36+1.64\times 0.27+2.87\times 0.21+6.14\times 0.15+12.29\times 0.09+32.77\times 0.05$$

$$Surface\ area = 5.6008\ m^2/kg$$

The theoretical bitumen film thickness is calculated as

$$T = \frac{b}{100-b} \times \frac{1}{P_b} \times \frac{1}{SAF}$$

T – is the bitumen film thickness (m)

P_b – is the density of the bitumen (kg/m^3) – 1.01 × 1000

SAF – Surface area factor (m^2/kg)

b – bitumen content (%) – 5.2%

$$T = \frac{5.2}{100-5.2} \times \frac{1}{1.01 \times 1000} \times \frac{1}{5.6008}$$

$$T = 0.000009696\ m$$

$$T = 9.696\ \mu m$$

The film thickness was calculated as 9.7 µm at an optimum binder content of 5.2%. The studies have shown that at least 6 to 8 µm is the minimum film thickness required for the mix to be durable. Film thickness can be used as a validation criterion in arriving at the Optimum bitumen content. This can be verified only, when the binder content is low and when the film thickness is less than 8 µm, and not to reduce the bitumen content, when the film thickness is higher, as in the case of the above example.

After testing the aggregate and bitumen for the requirements, the two materials have to be mixed at the right temperatures to obtain a durable bituminous mix.

CHAPTER 6

BITUMINOUS MIX DESIGN AS PER MARSHALL METHOD

6.1 Introduction

The Marshall method of mix design is followed for arriving at the optimum bitumen content for dense graded bituminous mixes such as Bituminous Concrete (BC), and Dense Bituminous Macadam (DBM). Laboratory bituminous mix is prepared to measure the bulk specific gravity (G_{mb}), and the maximum specific gravity of the mix (G_{mm}). These values will be used for calculating the volumetric properties, such as air voids, voids in mineral aggregate, and voids filled by bitumen. To determine the Optimal Binder Content (OBC), three compacted specimens should be prepared at five different bitumen contents and tested for various volumetric properties and strength parameters. In general, the optimum binder content should be selected at 4 percent air void content. The bituminous mix specimens are also used for carrying out the moisture sensitivity tests and other performance tests. For NMAS greater than 26.5 mm, a modified Marshall method with 150 mm diameter specimens should be prepared for mixes with NMAS 37.5 mm. A detailed procedure is available in ASTM D5581. However, the procedure is similar to the Marshall mix design method except for a few changes that are given below due to the change in the specimen size:

i. The 149.4 mm diameter flat tamping face hammer weighs 10.2 kg.

ii. A mechanically operated device is preferred for a drop height of 457 mm.

iii. The specimen should be generally 152.4 mm diameter and 95.2 mm height.

iv. The mix weight should be around 4,050 g.

6.2 Dense Graded Bituminous Mixes

Generally, the dense-graded bituminous mixes will have the voids in mineral aggregates (VMA) in the range of 11 – 15 %, and the air void content of around 4%. The Optimum Binder Content ranges from 4.0 – 5.4% (by the weight of mix). The Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) are the commonly adopted bituminous mixes in India. The aggregate gradations for DBM 1, DBM 2, BC 1, and BC 2 are given in **Table 6.1.** The gradation given in **Table 5.1** is in line with IRC:111-2009. It shall be noted that the gradation to be optimized to achieve a smoother gradation curve as shown through **Figs. 6.1, 6.2, 6.3** to **6.4**, for DBM 1, DBM 2, BC 1 and BC 2 gradations, respectively.

Table 6.1 Aggregate Gradation for Dense Graded Mix (IRC:111-2009)

Specification	DBM	DBM	BC	BC
Grading	1	2	1	2
Nominal maximum aggregate size*	37.5 mm	26.5 mm	19 mm	13.2 mm
Layer Thickness	75-100 mm	50-75 mm	50 mm	25-40 mm
IS Sieve size (mm)	Cumulative Percent by weight of total aggregate passing			
45.0	100			
37.5	95-100	100		
26.5	63-93	90-100	100	
19.0	-	71-95	90-100	100
13.2	55-75	56-80	59-79	90-100
9.5	-	-	52-72	70-88
4.75	38-54	38-54	35-55	53-71
2.36	28-42	28-42	28-44	42-58
1.18	-	-	20-34	34-48
0.600	-	-	15-27	26-38
0.300	7-21	7-21	10-20	18-28
0.150	-	-	5-13	12-20
0.075	2-8	2-8	2-8	4-10
Bitumen Content (Min) **	4.0%	4.5%	5.2%	5.4%

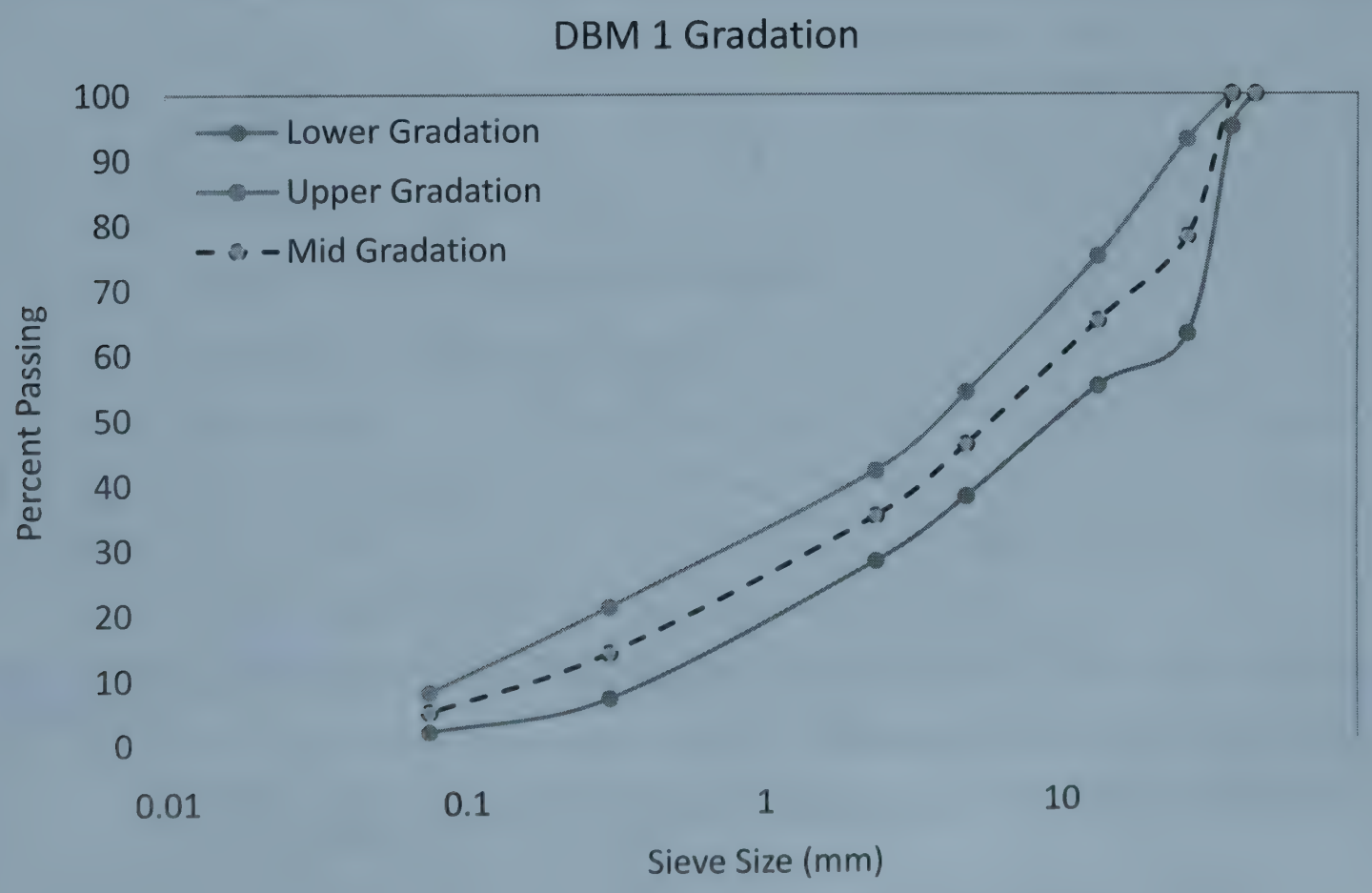


Fig. 6.1 Aggregate Gradation Chart for DBM 1

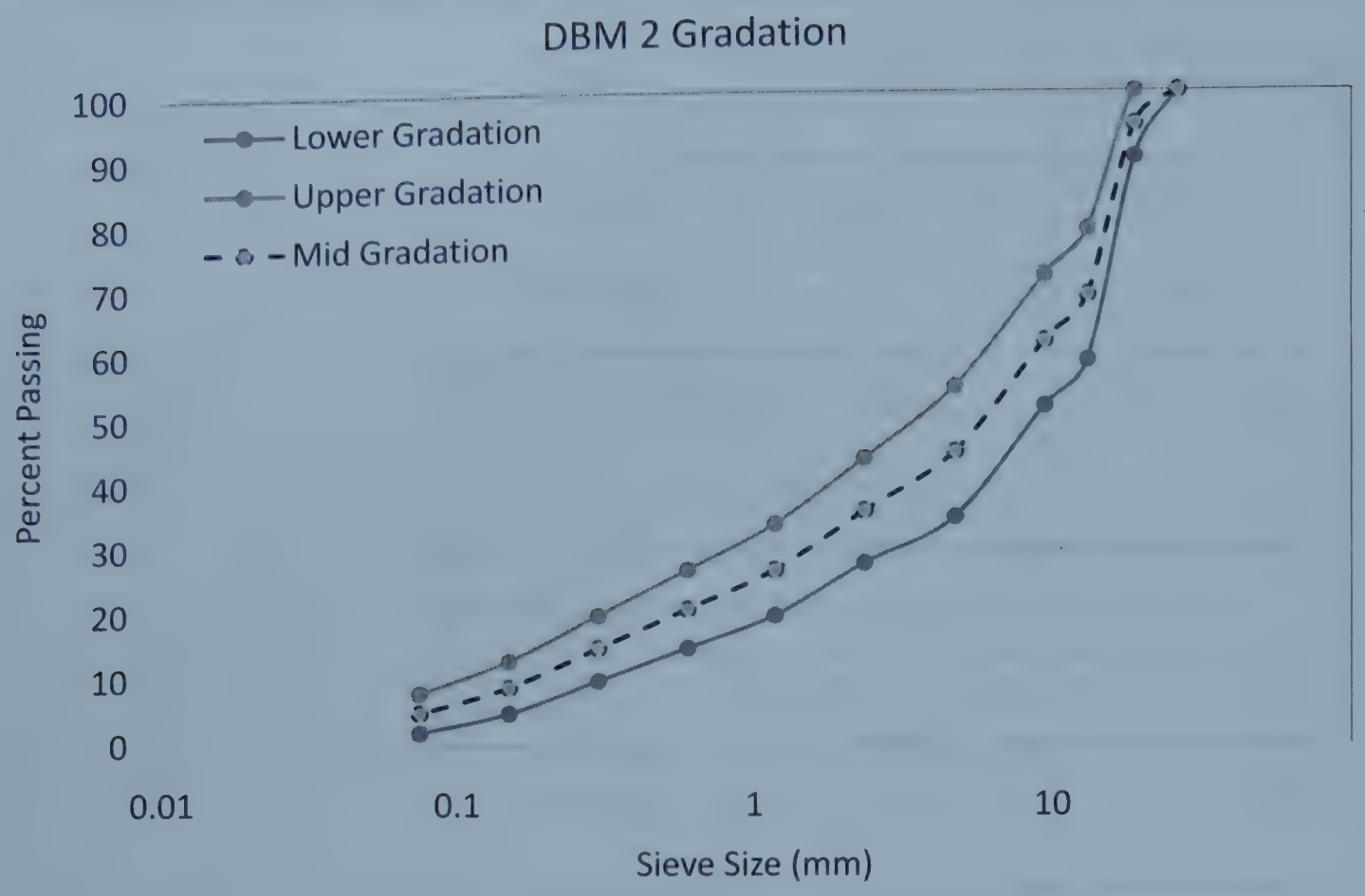


Fig. 6.2 Aggregate Gradation Chart for DBM 2

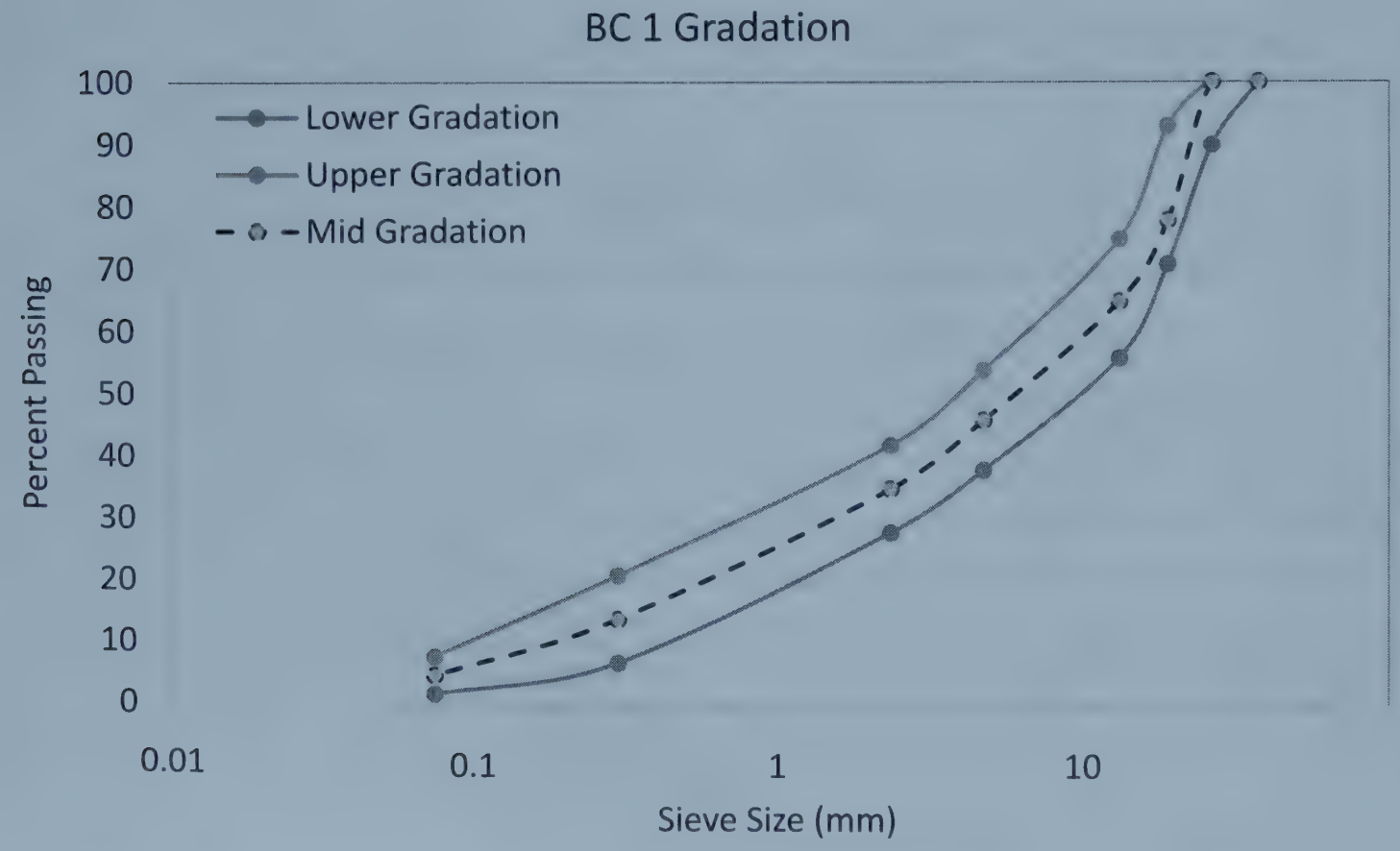


Fig. 6.3 Aggregate Gradation Chart for BC 1

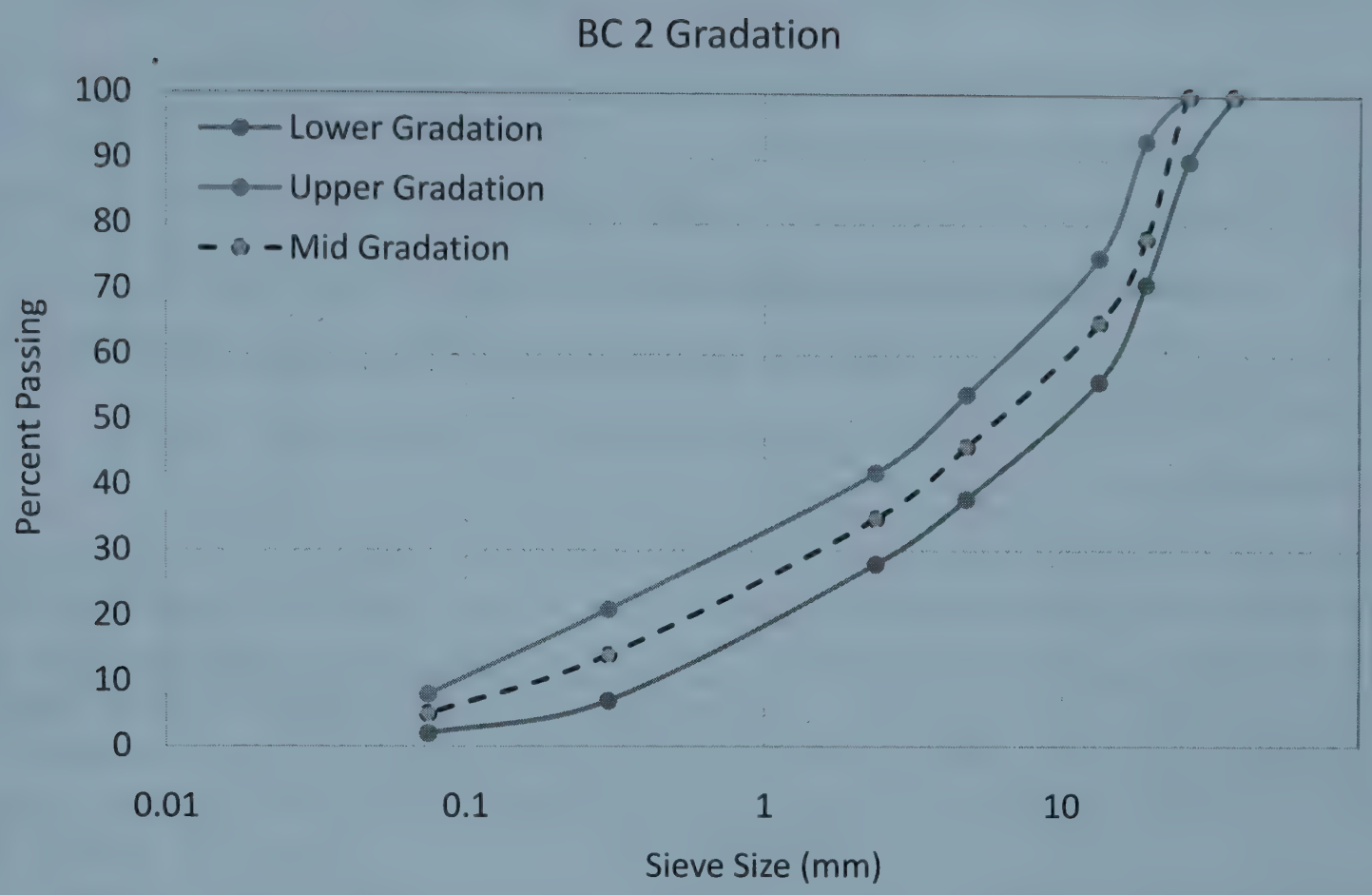


Fig. 6.4 Aggregate Gradation Chart for BC 2

6.3 Factors Influencing the Performance of Bituminous Mixes

Following are the factors essential for the performance of bituminous mixes:

- Workability
- Tender mix
- Durability
- Stiffness
- Resistance to permanent deformation
- Resistance to fatigue cracking
- Permeability
- Thermal fracture

6.3.1 *Workability/Compactibility*

Workability refers to the ease with which the mix can be handled, placed, and compacted in the given conditions.

- Mixtures with a high proportion of coarse particles are prone to segregation and may be difficult to compact.
- Workability can also be affected by too much or too little filler in the mix.
- The mix becomes less workable when the temperature is too low.

Workability can be improved for a given aggregate gradation by:

- Increasing the binder content.
- Reducing the binder viscosity.
- Limiting the NMAS to less than one-third the layer thickness.
- Compacting at the right temperature.

For Marshall Mixture Design determining the air void content will serve as one of the indicators for quantifying workability of the Mix.

6.3.2 *Tender Mix*

A tender mix is the one which gets shoved under turning loads. This can be observed in the field during compaction when the mix forms ripples in front of the rollers. The aggregate gradation used in the mix design determines whether the mix is tender or rut-resistant. The material between 4.75 mm and 0.15 mm sieves, influence the tenderness of the mix and hence, to be carefully controlled. A smooth grading line between 4.75 mm and 0.15 mm is preferable than a grading line with a hump between 0.6 mm and 0.3 mm sieve. In the gradation curve, a presence of "hump" between 4.75 mm and 150 µm, sieve sizes should be undesirable, and are the root cause for tenderness of the mix. The hump typically has its presence near the 600 µm sieve. This problem can be easily detected in 0.45 power gradation chart (followed in the Superpave mix design procedure). Mix tenderness can be controlled by resetting the gradation line, to obtain a smooth line.

A mix which shoves under the roller during the compaction is called a tender mix. Tender mix results from bitumen viscosity and aggregate gradation. The main reasons for tender mixes are given in **Table 6.2.**

Table 6.2 Tender Mixes Causes and Remedial Measures

Sl No.	Causes of tender mix	Remedial measures
i.	High mix temperature	Allow the mix to cool and then compact
ii.	High bitumen content	Reduce the bitumen or increase the filler
iii.	Rounded aggregate	Use crushed aggregate
iv.	Excessive fine aggregate in the range of 300 to 600 µm	Check for fine aggregate gradation. Also, ensure there is no moisture in the fine aggregate.
v.	Insufficient filler passing 75 µm	Increase the filler as per the JMF, filler should have at least 2% hydrated lime, frequent cleaning of bag house filter is must.
vi.	Too much or too less tack coat leading to poor bonding	Cleaning the spray bar at the end of the day
vii.	Poor compaction techniques	Follow the rolling pattern. Mixes that are tender under a steel wheel roller becomes less tender with the use of a pneumatic tyre roller
viii.	Mixes contaminated with petroleum products	Care must be taken to avoid contamination due to diesel or other oils, during construction

6.3.3 *Durability*

Durability of the bituminous mix is its ability to resist binder ageing, loss of volatiles, disintegration of the aggregate, and stripping of binder.

The durability of mixes can be improved by using:

i. Using an appropriate binder with 6 to 8 µm film thickness;

ii. Dense aggregate packing, with low air void content;

iii. Sound, durable and strip resistant aggregates;

iv. By using hydrated lime and/or Anti-stripping additives.

6.3.4 *Moisture Sensitivity*

Moisture sensitivity of the bituminous mixtures shall be conducted as per AASHTO T 283 and IRC:111-2009. A total 6 compacted specimens should be prepared at OBC with an average air voids of 7.0 ± 0.5 percent divided into two subsets. The first subset (three specimens) was subjected to conditioning, whereas the second subset (three specimens) was tested without any conditioning. The conditioning done by vacuum saturating with water before one freeze cycle (16 h at -18 ^{o}C) and one thaw cycle (24 h at 60 ^{o}C) in a water bath. Indirect tensile strength (ITS) was determined for both the conditioned and unconditioned specimens at a temperature of 25 ^{o}C using equation 6.1. The ITS shall be determined using the below given formula:

$$ITS = \frac{2P}{\pi Dt} \qquad \textit{Eq 6.1}$$

ITS – Indirect tensile strength (kPa)

P - maximum load (kN)

D – diameter of specimen (mm)

t - thickness of specimens (mm)

The Tensile Strength Ratio (TSR) shall be calculated by ratio of the conditioned ITS to un conditioned ITS value. The TSR should be determined using equation 6.2.

$$TSR = \frac{ITS_{\,conditioned}}{ITS_{\,un\text{-}conditioned}} \qquad \textit{Eq 6.2}$$

6.3.5 *Top-down Cracking*

The longitudinal surface cracks which initiates on the pavement surface (or close to the surface) and then propagate downwards and are generally referred as top-down cracking. They occur prematurely within the first 2 to 3 years of construction. The main causes for top-down cracking is given in **Table 6.3.**

Table 6.3 Causes and Remedial Measures for Top-Down Cracking

Sl No.	Causes of Tender Mix	Remedial Measures
i.	High horizontal tensile strain on the surface due	Use of harder grade bitumen or modified bitumen
ii.	Age hardening of surface layers due to oxidation	Use of hydrated lime to reduce oxidation and stripping of aggregate
iii.	A low stiffness upper layer due to high surface temperature	Use of lime also stiffens the mix to avoid top-down cracking at higher pavement temperature

6.3.6 *Stiffness*

The ability of the bituminous mix to carry and spread traffic loads to below layers is determined by its stiffness. The key factors that affects the stiffness of bituminous mix are:

- Traffic loading time
- Temperature
- Binder content and binder rheology
- Aggregate packing

The Stiffness of Bituminous Mix can be determined by computing the resilient modulus M_R using the equation: The Indirect Tensile Strength (ITS) of the Mix should be conducted as per AASHTO T283 at 35°C and the Resilient Modulus (M_R) should be determined using equations 6.3 and 6.4, for DBM and BC, respectively:

$$M_R = 11.088 \times ITS - 3015.80 \qquad \text{Eq 6.3}$$

(If the diameter of specimen is 150 mm for Bituminous Base/Binder layer)

$$M_R = 1.1991 \times ITS + 1170 \qquad \text{Eq 6.4}$$

(If the diameter of specimen is 100 mm and for mixes with modified bitumen)

6.3.7 *Performance Criteria for Bituminous Mix Rutting*

Rutting failure in bituminous layers, is one the very common premature distresses observed in flexible pavements with thick bituminous layers. The wheel tracking test has been found to be very useful test to assess the rutting performance of mixes. Several road agencies, have established the pass/fail criteria for bituminous mixes, to withstand the design traffic level, without undergoing severe rutting in the field (20 mm for Indian conditions, IRC:37-2018). These pass/fail criteria have been developed by laboratory and field performance monitoring of bituminous mixes. The laboratory and field rutting performance of dense graded surface course mixes was monitored by IIT Kharagpur. The test sections were constructed on National Highway 60 (NH60). After field monitoring, IIT Kharagpur has proposed pass/fail performance criteria for dense graded surface course mixes (Radhakrishnan et al, 2018). To evaluate the appropriateness of the mix in resisting rutting, the dry wheel tracking test should be carried out at 60°C in the laboratory (BS EN: 12697-26, 2003). The test should be carried out on 150 mm diameter cylindrical samples

compacted to 7% air voids. The test applies a wheel load of 700 N, and is carried out at 25 load cycles per minute. The accumulated rut depth at the end of 20,000 cycles is compared with the limiting values proposed for different traffic levels. For the mix to perform satisfactorily in the field while enduring the design traffic, observed wheel tracking rut depth shall not exceed the limiting value proposed in **Table 6.4.** Other wheel tracking devices such as Hamburg wheel tracking may also be used. The limiting wheel tracking rut depths proposed in **Table 6.4**, were determined for a terminal rut depth of 20 mm in the field.

Table 6.4 Wheel Tracking Values at 60°C for different Traffic (Radhakrishnan, 2018)

Traffic Level, msa	Limiting Rut-Depth (mm) for 20 mm Field Rut-Depth (maximum)
<10	6.4
≥10<30	4.0
≥30<50	2.7
≥50	1.9

6.3.8 *Performance Criteria for Fatigue Cracking*

Resilient modulus of bituminous mixes depends upon the grade of binder, aggregate gradation, and air voids. The modulus values should be obtained by carrying out the indirect tensile fatigue tests at 35°C as per ASTM: D739-09. For the DBM mixes 150 mm diameter specimens should be used because of the larger size aggregates. An indicative resilient moduli (maximum) for DBM 1, DBM 2, BC 1, and BC 2 mixes are given in **Table 6.5** (IRC:37-2018) for reference. The moduli values given in **Table 5.5** is based on the tests carried out as per ASTM:4123, upgrade now to ASTM: D7369-09. The mixes with modified binders are, in general, expected to have better fatigue and rutting performance and durability compared to conventional mixes.

Table 6.5 Indicative Resilient Moduli Values (MPa) of Bituminous Mixes 35°C

Mix Type	Resilient Moduli (MPa)
BC and DBM for VG10 bitumen	1000
BC and DBM for VG30 bitumen	2000
BC and DBM for VG40 bitumen	3000
BC with Modified Bitumen (IS:15462-2019 and IS:17079-2019)	1600

6.3.9 *Permeability*

The permeability of a bituminous mix refers to the amount of air, water, and water vapour that can pass through it. A low permeability in dense bituminous mix surfacing increases the durability, and protects the underneath layers from moisture damage. The Permeability can be determined in accordance with EN 12697-19:2020 (Part 19). The factors that reduces permeability are:

- Higher binder content with higher film thickness
- Dense aggregate packing
- Well compacted bituminous layers

6.4 Four Stages of Bituminous Mix Testing

6.4.1 *Preliminary Design Testing*

The primary goal of preliminary design testing is to see if potential suppliers can offer aggregate of sufficient quality to make a paving mix that meets the specification gradation and mix design requirements. Bitumen must also fulfil specifications and be suitable with the aggregates available. The aggregate gradation should be close to the median of gradation limits.

6.4.2 *Job Mix Formula*

Testing is done during the mix design to establish the optimum amount of various aggregate fractions to produce a bituminous mix. The gradation of combined aggregate materials and the selected bitumen content are determined by the job-mix formula. Certain variances in the mix are unavoidable while preparing the paving mix in a plant. Tolerances in a job-mix formula allow for appropriate gradation and bitumen content changes (MoRT&H Table 500-13).

6.4.3 *Job-Mix Control Testing*

Job-mix control testing is carried out at the commencement of plant production and in conjunction with the job mix formula. This testing should be carried out on bituminous mixes prepared at the plant site. This is necessary because the Bituminous mix produced in the plant may alter the aggregate's characteristics. This will be a double-check to assess that the plant is calibrated. This type of testing, checks whether the paving mix produced using the job mix formula fits the construction requirements.

6.4.4 *Routine Construction Control*

During pavement construction, construction control testing is performed as a routine and periodic item of inspection. The design properties of random samples of the hot paving mix are examined. The results of these tests are compared to the job-mix control tests, and the overall specification criteria. When abnormalities arise, and the job mix formal restrictions are exceeded, suitable plant corrections are required. It's significance is highlighted because the results serve as the foundation for the mix's final acceptance or rejection.

6.5 Mixture Design Essentials – Optimum Binder Content Determination

The next step after arriving at the JMF is determining the Optimum Binder Content for the supposedly finalized gradation. **Fig. 6.5** shows a schematic representation of the volumetric parameters of a compacted bituminous mix. Important terminologies and test procedures for determining various characteristics of bituminous mix components are given in **Tables 6.6** and **6.7**.

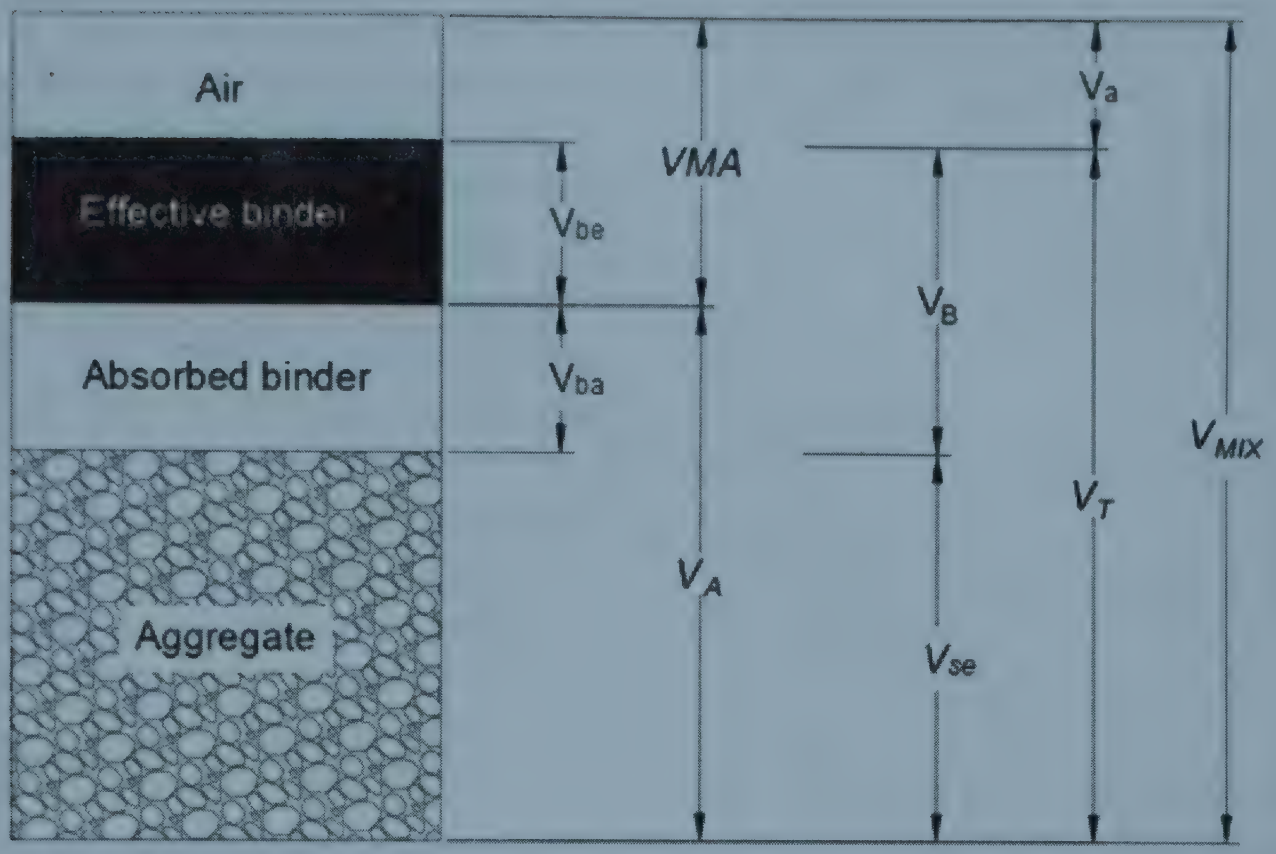


Fig. 6.5 Volumetric Parameters of Compacted Bituminous Mix Specimen

Where,

V_a	:	Volume of air-voids
VMA	:	Volume of voids in mineral aggregate
V_b	:	Total volume of binder within the Bituminous mix
V_{ba}	:	Volume of absorbed binder
V_{be}	:	Effective volume of binder
V_{sb}	:	Bulk volume of aggregate, including all permeable surface pores
V_{se}	:	Effective volume of aggregate excluding surface pores filled with binder
V_T	:	Total volume of binder and aggregate in the mix
V_{MIX}	:	Total (apparent) volume of compacted bituminous sample

Table 6.6 Density Parameters used in Volumetric Analysis

Parameter	Symbol	Definition
Bulk Specific Gravity of Aggregate	G_{sb}	Expressed as the ratio of mass per unit volume of aggregate particles, including the impermeable (internal) and permeable(surface) voids to the mass per unit volume of water at the reference temperature
Apparent (True) Specific Gravity of Aggregates	G_{sa}	Expressed as the ratio of mass per unit volume of the impermeable (excluding air void) portion of aggregate at a given temperature to the mass per unit volume of distilled water.

Effective Specific Gravity of Aggregates	G_{se}	Expressed as the mass per unit volume of permeable material (excluding absorbed bitumen) portion of aggregate at a given temperature to the mass per unit volume of distilled water.
Water absorption	W_a	Difference in mass between the saturated surface-dry condition and the oven-dry condition of a given volume of aggregate
Specific Gravity of binder	G_b	The bulk specific gravity of the binder, expressed in kilogram per cubic meter (g/m^3)
Bulk specific gravity of mix	G_{mb}	Mass per unit volume, including the air-voids, of a bituminous mixture at a known test temperature, expressed in kilograms per cubic meter (kg/m^3)
Maximum Specific Gravity of the mix (RICE method)	G_{mm}	Mass per unit volume of a voids-less bituminous mixture at a known test temperature

Note: *It is recommended that the specific gravity of binders should be determined in accordance with the Indian Standards. When a modified bitumen is used, the specific gravity of the bitumen should be provided by the supplier (in compliance to IRC:SP:53-2010, IS:15462-2019 and IS:17079-2019 or latest).*

Table 6.7 Parameters used in Volumetric Analysis

Parameter	Symbol	Definition	Formula
Voids in the mix	V_a	Difference between the Gmm and the Gmb expressed as a percentage of the Gmm	$V_a = \left[\frac{G_{mm} - G_{mm}}{G_{mm}}\right] \times 100$
Maximum Specific Gravity of Mix	G_{mm}	The Specific Gravity of the Loose (Un-compacted) Mix (Highest Specific Gravity an Asphalt Mixture can achieve)	$G_{mm} = \frac{100}{\left[\left(\frac{p_S}{G_{se}} + \frac{p_b}{G_b}\right)\right]}$
Effective Specific Gravity of Aggregates	G_{se}	Ratio of oven-dry mass per unit volume of aggregates (including impermeable volume + water permeable not filled with bitumen) to the mass per unit volume of water at the reference temperature	$G_{se} = \frac{Pmm - p_b}{\left[\frac{Pmm}{G_{mm}} - \frac{p_b}{G_b}\right]}$
Absorbed binder contents	P_{ba}	Percent absorbed binder content (%)	$P_{ba} = \left[\frac{1}{G_{sb}} - \frac{1}{G_{se}}\right] \times G_b \times 100$
	V_{ba}	Volume of binder absorbed into the pores (permeable voids) in the aggregate	$V_{ba} = \frac{P_{ba}}{G_b} \times G_{mb}$

Effective binder content	P_{be}	Percentage of effective binder in the mix (i.e. the total binder less the binder absorbed)	$P_{be} = P_b - P_s \times \left[\frac{P_{ba}}{100}\right]$
	V_{be}	Volume of effective binder expressed as a percentage of the volume of the bulk mix	$V_{be} = \frac{P_{be}}{G_b} \times G_{mb}$
Voids in the mineral aggregates	VMA	Volume of voids in the bulk mix expressed as the % difference between the volume of aggregate and the bulk volume of the mix	$VMA = \left[100 - \frac{P_s}{G_{sb}} \times G_{mb}\right] \times 100$
Voids filled with bitumen	VFB	Percentage of voids in the bulk mix filled with binder	$VFB = \left[\frac{VMA - V_a}{VMA}\right] \times 100$

6.6 Marshall Mixture Design

The Marshall method of mixture design governs the evaluation of volumetric properties required for determining the optimum binder content. The cylindrical specimens required for the evaluation are prepared using the Marshall compactor. Five different bitumen content (spaced at an interval of 0.5%) are evaluated for various volumetric and strength parameters in order to determine the optimum binder content (OBC) for a particular aggregate gradation. The OBC is determined by engineering judgement, which is based on traffic, climate, and familiarity with the local materials. In most circumstances, the OBC should be selected for a target air void content (V_a) of 4 %. At the same time, the volumetric requirements relating to the VMA and VFB should also be satisfied.

6.6.1 *Outline of the Method*

The preparation of cylindrical specimens is the first step in the Marshall method. Prior to preparation, the following points shall be taken care of:

- All materials recommended for use, should meet the physical requirements;
- The aggregate blend combinations meet the specified grading requirements;
- The bulk specific gravity (G_{sb}) of aggregate, and the specific gravity of bitumen (G_b). should be obtained compute density and other volumetric properties.

Preparation of the Sample

The specimen diameter (100 mm or 150 mm) is chosen based on the NMAS. Three identical specimens shall be prepared at each trial binder content and the preparation procedure shall comply to the IRC:111-2009. The mixing procedure involves preheating the aggregates and bituminous binder prior to mixing. Samples should be mixed and compacted at the suitable mixing and compaction temperatures, depending on the binder type or grade. Compact the specimens soon after short-term ageing by giving 75 (100 mm diameter) or 112 blows (150 mm diameter) on both faces of the specimens. The mixing temperature is defined as the temperature range that results in a binder viscosity (rotational) of 0.17±0.02 Pa.s, while the viscosity for compaction temperature is 0.28±0.03 Pa.s. The mix should meet the requirements given in **Table 6.8**.The details of the Marshall mix design procedure and the performance tests requirements for varying design traffic is given in **Annex I**.

Table 6.8 Requirement of Dense Graded Bituminous Mix

Properties	Viscosity Grade Paving Bitumen	Modified Bitumen		Test Method
		Hot Climate	Cold Climate	
Compaction level (Number of blows)	75 blows on each face of the specimen			
Minimum stability (kN at 60°C)	9	12	10	AASHTO T245
Marshall flow (mm)	2-4	2.5-4	3.5-5	
Marshall Quotient (stability/flow)	2-5	2.5-5		
% Air-voids	3-5			ASTM D2041
% VFB*	65-75			MS-2
Tensile Strength Ratio	80% (Minimum)			AASHTO T283
Coating of Aggregate Particles with bitumen	95% (Minimum)			IS: 6241
% Voids in Mineral aggregate VMA (MoRT&H)				
Nominal Maximum Particle size (mm)	Min. % VMA related to designed % air-voids			
	3	4	5	
9.5	14	15	16	
13.2	13	14	15	
19.0	12	13	14	
26.5	11	12	13	

** For rich bottom bituminous binder/base layer, the VFB should be 65-80%.*

Table 6.9 shows the typical values for mixing, laying, and rolling temperatures for bituminous mixes. Specimens should be short-term aged in an oven at 135°C for 2 hours. Make sure that the sample temperature does not drop below the compaction temperature.

Table 6.9 Mixing, Laying and Rolling Temperatures for Dense Mixtures (°C)

Bitumen Viscosity Grade	Bitumen Temperature	Aggregate Temperature	Mixed Material Temperature	Laying Temperature	*Rolling Temperature
VG-40	160-170	160-175	160-170	150 min	100 min
VG-30	150-165	150-170	150-165	140 min	90 min
VG-20	145-165	145-170	145-165	135 min	85 min
VG-10	140-160	140-160	140-160	130 min	80 min
*Rolling must be completed before the mat cools to these minimum temperatures					

Note: In this table, only values for continuously graded mixtures are presented.

Testing of Specimens

The Marshall method of mix design includes two key aspects: a density-voids analysis, and a stability-flow test, using compacted test specimens. The testing involves radially loading the cylindrical specimen at a constant deformation rate of 50 mm/min. Prior to testing, the specimen is conditioned to achieve a temperature of 60°C. The stability of the test specimen is the maximum load resistance in kilo Newton (kN) that the standard test specimen will achieve at 60°C, when tested as described. The flow value is the overall deformation in the specimen measured in millimetres, between the zero-load and highest load point during the stability test. A typical example for the design of a dense bituminous mix is given in **Annex II**.

CHAPTER 7

MIXTURE DESIGN USING RECLAIMED ASPHALT PAVEMENT (RAP)

It has been well established that the older bituminous pavement, once milled, can be reused for the construction of new pavements. The amount of Reclaimed Asphalt Pavement (RAP) in the bituminous mixture will determine the nature of attributes to be determined before using the RAP material. Bitumen content and gradation will be required for all levels of RAP.

7.1 Determination of Bitumen Content and Final Gradation

Regardless of the amount of RAP that is used in the mixture, the mix design technologist will need to know the binder content of the RAP, so that the total binder content (RAP binder plus virgin binder) can be properly determined. There are two principal ways of determining the binder content of the RAP:

i. Ignition oven procedure and solvent extraction. The ignition oven procedure is detailed in AASHTO T 308, "Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method."

ii. The solvent extraction procedure is detailed in AASHTO T 164, "Quantitative Extraction of Asphalt Binder from Hot-Mix Asphalt (HMA)."

iii. The details of binder extraction procedure is given in **Annex III**.

The recovered aggregate should be saved for determining the gradation using AASHTO T 30, "Mechanical Analysis of Extracted Aggregates." The volumetric parameters of RAP added bituminous mixes is shown in **Fig. 7.1**.

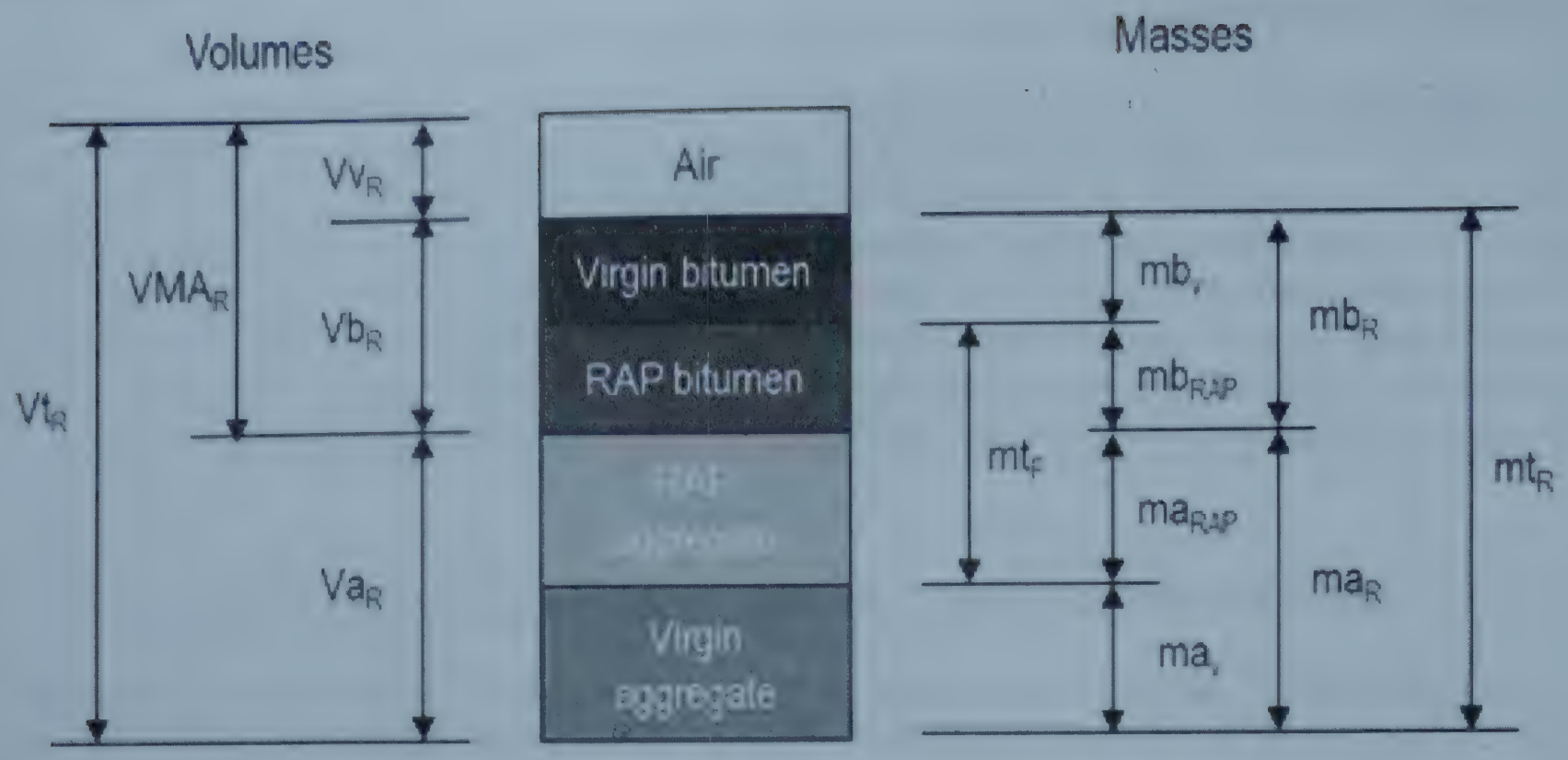


Fig. 7.1 Composition of a Recycled Bituminous Mix

7.2 Determination of Optimum RAP Percentage

The selection of RAP percentage should be based on the Viscosity-Blending Charts and the steps are as follows:

i. The binder content in the RAP shall be determined and the extracted binder shall be retained for determining the blending percentage.

ii. A Target Viscosity (V_{Targ}) for the Optimum Blend should be set. If a blend of VG30 and RAP binder has a target binder viscosity corresponding to that of VG40, the value of V_{Targ} should be in the range of 4000±800 Poise (**Fig. 7.2**)

iii. The kinematic Viscosity of RAP and Virgin Binder should be determined at 60 ^{o}C.

iv. **Fig. 7.2** shows the semi-log viscosity-blending chart wherein the X-axis indicates the ratio of virgin binder to total mix binder, while the logarithmic Y-axis indicates the viscosity in Poise.

v. After determining the viscosities of RAP and virgin binder (0 and 100% V/T resp.) and plotting against the respective proportions, the plotted points shall be joined to form a line.

vi. The intersection of the coinciding viscosity and V_{Targ} lines forms a point, and its abscissa should be set as the Target Blend Proportion/RAP Content.

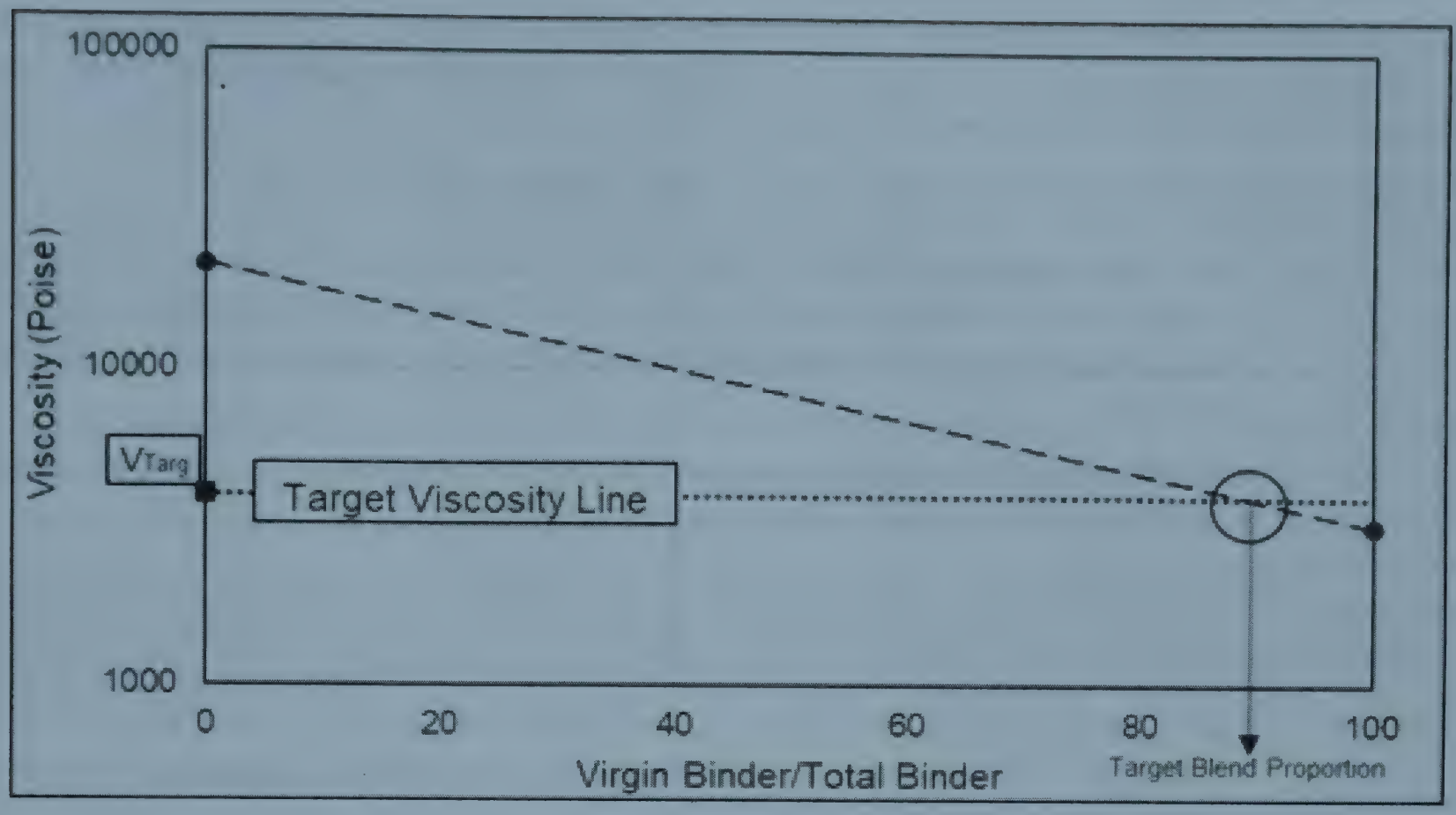


Fig. 7.2 Viscosity-Blending Chart Example

7.3 Bulk Specific Gravity (BSG) of RAP Aggregate

It is necessary to calculate the bulk specific gravity of RAP aggregate, G_{sb}^{RAP} because the mix VMA is calculated using the bulk specific gravity of RAP and virgin aggregate, combined. The BSG of RAP aggregate cannot be measured directly. If the source of RAP is known and the original construction records are available, it is easy to obtain the BSG of RAP aggregate. If the original construction data is not available, then a three-step technique is recommended for determining the BSG of RAP aggregate:

i According to AASHTO T 209, calculate the maximum theoretical specific gravity of the RAP mix, G_{mm}^{RAP}.

ii The specific gravity of RAP aggregate can be calculated using the maximum specific gravity of the RAP mix, G_{mm}^{RAP}, the RAP binder content, and by using the RAP specific gravity (G_b).

iii The bulk specific gravity of the RAP aggregate can be calculated using the effective specific gravity of the RAP aggregate G_{se}^{RAP} as given in equation 7.1. However, this will overestimate the combined aggregate Gsb. Furthermore, utilising higher RAP content may amplify the inaccuracy in converting G_{se}^{RAP} to G_{sb}^{RAP}.

$$G_{se}^{RAP} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \qquad \textit{Eq 7.1}$$

iv Assume a typical value for bitumen absorption, P_{ba}, and use it to determine the bulk specific gravity of RAP aggregate, G_{sb}^{RAP}, using the estimated G_{sb}^{RAP} based on mix design expertise for the specific location as given in equation 7.2.

$$G_{sb}^{RAP} = G_{se}^{RAP} / \left[\frac{P_{ba} - G_{se}^{RAP}}{100 G_b} + 1\right] \qquad \textit{Eq 7.2}$$

If the bitumen absorption data is available from the previous records, P_{ba} data can be obtained from the previous data. If no previous data is available, a P_{ba} value can be calculated as a percentage of 60–65 % water absorption value.

The RAP aggregate's combined specific gravity can be calculated as follows:

- The RAP aggregate obtained after a solvent extraction or ignition oven method is used for the calculation of RAP Specific Gravity. Individual specific gravity tests are performed by separating the RAP aggregate in to coarse and fine fractions.
- If RAP is limited to 20%, no rejuvenators are required, and the RAP can be added as cold RAP in to a pug mill.
- If 20 to 50% RAP has to be used in the design of bituminous mix, a suitable rejuvenator has to be added. The rejuvenator has to be used and the mix design has to be carried out in the laboratory. If 20-50% RAP has to be used, the RAP has to be heated using a double barrel hot mix plant or a parallel dryer drum for heating the RAP. It is recommended to use the process of fractionation when 20-50% RAP material is used.
- Through the process of fractionation, the RAP material should be separated based on the sieve sizes, similar to the virgin aggregate. The fractionation process helps in reducing the variation in the RAP gradation. Higher fine aggregate from RAP leads to tender mixes, and the details regarding the tender mixes are given in Chapter 5.

A mix design example with 30% RAP material is given in **Annex IV**.

CHAPTER 8

IMPORTANT POINT TO BE CONSIDERED DURING MIX DESIGN

The Marshall compaction applied in the design process should be identical to the density obtained in the field due to secondary compaction. Therefore, the Marshall specimens are compacted by giving 75 blows on both faces of the specimens for design traffic greater than 1 Million Standard Axles (msa) as per MS-2. However, the roads with higher traffic are common in India, and the loading conditions may be considered as severe. Therefore, the concept of refusal density may be adopted for traffic greater than 50 msa.

8.1 Refusal Density to ensure Resistance against Rutting

Bituminous mixes, offers a good riding surface that acts as a structural layer for load spreading. However, on several occasions, mixes undergo deterioration, namely:

- Raveling
- Rutting; and
- Cracking

Rutting failure is a major cause of concern for road agencies in areas where there are slow moving overloaded trucks. In addition, the problem gets aggravated if the pavement temperature is higher. The filler binder ratio, also plays an important role in controlling rutting, an ideal value of 0.8 to 1.0 is preferred. If the filler binder is greater than 1, the binder may be reduced to achieve the rut resistant mixture and verified for the volumetric properties. Thus, incorporating Refusal density into the design of bituminous mixes helps in achieving the rut-resistant mixes. To avoid premature rutting on a heavily trafficked (>50 msa) road pavement, the designed mixes should be tested for its durability at 2.5 percent air voids, using refusal density concept.

The mixes should be compacted to refusal density for achieving the maximum bulk specific gravity, where the air voids should not reduce below 2 percent. The refusal density should be done as per BS 598: Part 104:1989 or by extending the compaction to 250 blows on both faces. Additionally, it defines Percentage Refusal Density (PRD) as 'The ratio of the initial dried bulk density of the sample to the refusal density' expressed as a percentage. The refusal density and rutting tests as an additional feature in mix design will give rise to a performance based mix design (Sridhar et al. 2006, TRL, 2002).

8.1.1 *Recommended Mix Design Procedure*

Marshall specimens should be prepared at optimum binder content and ± 0.5 percent binder contents. These specimens should be subjected to vibratory compaction or extended Marshall compaction to establish the bitumen content at which 2.5 percent air voids is retained at refusal density. If the air voids are less than 2.5 percent at refusal, the gradation of aggregate should be altered, by increasing the VMA, for obtaining a viable mix.

8.1.2 *Test Procedure*

The testing of design mixes in pre-construction field trials is extremely important. At least three trial lengths should be constructed with bitumen contents at the laboratory optimum for refusal density (2.5 percent voids in mix) and at 0.5 percent above and below the optimum. The trials should be used to;

a. Determine the rolling pattern required to obtain a satisfactory density

b. Establish that the mix has satisfactory workability to allow a mean of at least 95 percent and an absolute minimum of 93 percent of refusal density should be achieved after rolling

c. Obtain 150 mm diameter cores for finding the Percent Refusal density (PRD).

After measuring the density of trial field cores, they should be subjected to refusal compaction. This is important because the road rollers may have produced a different particle orientation compared to that produced in the laboratory tests. The field cores are re-heated and compacted to refusal, to arrive at the maximum binder content at 2.5 percent air voids, to confirm the refusal density.

8.1.3 *Performance of Bituminous Mixes*

Rutting in bituminous mixes is a serious form of distress as the entire bituminous layer must be removed/rectified before rehabilitation. This occurs due to underestimated secondary compaction that occurs due to heavy moving traffic. The slow moving heavy-traffic significantly reduces the

air void content (V_a), leading to premature rutting failure in the bituminous layers. Thus, to reduce the rutting failure, it is necessary to maintain the air voids content greater than 2.5 percent. An appropriate laboratory design compaction level should be followed is given **Table 8.1**.

Table 8.1 Critical Values of V_a after Secondary Compaction

V_a in bituminous mixes	Effect
Greater than 8%	Extremely permeable to air and water. Accelerated oxidative ageing of bitumen in hot climatic regions
Greater than 5%	Highly permeable to air and are prone to oxidative ageing of bitumen
In between 4 to 5%	Target or design air voids
In between 2.5 to 5%	For a durable and stable mix
Less than 2.5%	Prone to rutting under heavy loading

8.1.4 *Effect of Refusal Density on Design Bitumen Content*

In the Marshall technique for designing bituminous mixes, the number of blows of the compaction hammer is an important parameter. The findings show how rutting can occur when secondary compaction under traffic is underestimated, resulting in air voids content less than the specified minimum value of 2.5%. For instance, using 75 blow compaction results in a design bitumen content of approximately 5.4% (BC 2) at air voids content of 4%.

At a bitumen content of 5.4 %, if the secondary compaction is equivalent to 120, and 250 Marshall hammer blows, the design air voids reduces to around 3.3%, and 2.2%, respectively. It is recommended that the design air void should be considered as 4% at 75 blows, on each face when the design traffic is higher than 5 msa. Applying this criterion, the design bitumen content should be adjusted accordingly, to have the air voids higher than 2.5%.

8.2 Design for Severe Sites

Without sufficient knowledge of the degree of secondary compaction that will occur on difficult locations, any choice of a Marshall compaction level becomes arbitrary. Because the aggregate structure cannot be compacted any further, compaction to Refusal density gives a 'reference density'. As a result, particle size distributions can be selected to provide the proper VMA, which will accommodate enough bitumen to ensure good workability during the construction phase while maintaining a minimum of 2.5% air voids.

The satisfactory mix is then checked for air-voids after refusal compaction, at 250 Marshall blows (Sridhar et al., 2004). The stability and flow of refusal specimens should be tested after conditioning the specimens for 6 hours in a water-bath at 60°C, and for one hour in a water both at 70°C before testing. The Marshall stability should conform to the minimum values specified in the MoRT&H Specifications.

In addition to this, the refusal density should be tested on regular basis during the mix design, and during work executions.

8.3 Recommendations

The following recommendations are made for adopting refusal density (>50 msa):

a) All gradation shall be as per the MoRT&H for selection of mixes.

b) The specimens should be compacted with 250 blows on each face to achieve refusal density.

c) The mixes at OBC should be selected based on 2.5±0.3% air-voids after refusal compaction. The stability and flow of refusal specimens should be tested after conditioning the specimens for 6 hours in a water-bath at 60°C, and for one hour in a water bath at 70°C before testing. This test should be performed in areas where the maximum air temperature is above 45°C.

d) The plastic deformation failure occurs in continuously graded mixes if the voids in the mix are below 2.5%. Therefore, the use of refusal density design is to ensure that, at refusal there is still 2.5% air voids. Also, at a few site locations the air voids will not reach 2.5%. In such cases, the refusal density concept should be used to ensure that the maximum binder content for good durability is obtained. All parameter should satisfy during the mix design as mentioned in **Table 8.2.**

Table 8.2 Parameters for Mix Design at Refusal Density

Sr. No.	Description	Requirements
1.	Marshall stability (ASTM Designation D-1559) determined on Marshall specimens compacted by 250 blows on each face.	9 kN (minimum for unmodified binders) 12 kN (minimum for modified binders)
2.	Marshall flow (mm)	2-4 mm
3.	Air-voids (V_A)	2.5±0.3%
4.	Minimum voids in mineral aggregates (VMA)	12-15%
5.	Voids filled by bitumen (VFB)	65-75 (DBM)* 65-75 (BC)
6.	Binder content (%) weight of total mix.	As given in Table 6.1

** For rich bottom bituminous binder/base layer, the VFB should be 65-80%.*

e) By adopting the refusal density design criteria for OBC, containing 2.5% of air-voids the durability of the mixes can be achieved.

CHAPTER 9

INTRODUCTION TO SUPERPAVE MIX DESIGN

In 1987, the Federal Highway Administration (FHWA) began a research for five-years to improve the performance of bituminous pavements. The result of this research study was the development of the Superpave (**SU**perior **PER**forming Asphalt **PAVE**ments) system. This system was developed to provide the field engineers a tool for improving the performance of the bituminous pavements considering the extreme traffic loading and climate. Superpave system consists of binder specification and mix design and volumetric analysis.

9.1 The following steps summarises the Superpave Mix Design Procedure:

i. selecting bitumen and aggregate materials that meet the design criteria.

ii. developing an aggregate blend that will meet the Superpave requirements.

iii. mixing and short-term ageing the bituminous mix.

iv. compacting specimens utilizing the Superpave Gyratory Compactor (SGC) according to expected traffic levels

v. analysing the volumetric properties of the mix

vi. selecting the best aggregate blend that meets the desired performance criteria for the mix, and

vii. mix performance testing for moisture sensitivity.

9.1.1 *Superpave Gyratory Compactor*

The main parameters governing the compaction effort are:

- the vertical pressure, 600 ±18 kPa;
- Specimen diameter, 150 mm
- the external angle of gyration of the mould, 1.25°
- the internal angle of gyration of the mould, 1.16 ±0.02°;
- gyration rate, 30.0 ±0.5 gyrations per minute; and
- the number of gyrations, variable – it is based on expected traffic level.

9.1.2 *Gyratory Calibration and Angle Verification*

Although, all parameters need to be regularly and accurately calibrated, the gyration angle has the greatest effect on specimen compaction. As the angle increases, the compaction effort increases. Likewise, if the gyration angle decreases, specimen compaction will decrease. Small variations in gyratory angle can result in considerable differences in the level of compaction. It is critical to maintain a well-calibrated compactor to assure no deviation in the internal gyration angle. The compaction parameters are shown in **Fig. 9.1**. While the mould gyrates, a constant consolidation pressure is provided to the sample during the fabrication of the SGC specimens. To provide specimens of consistent density, it is critical that the SGC maintain a constant angle of gyration during the compaction process. Variations in the angle of gyration can often be attributed for inconsistencies in the density of mix specimens produced by different SGCs.

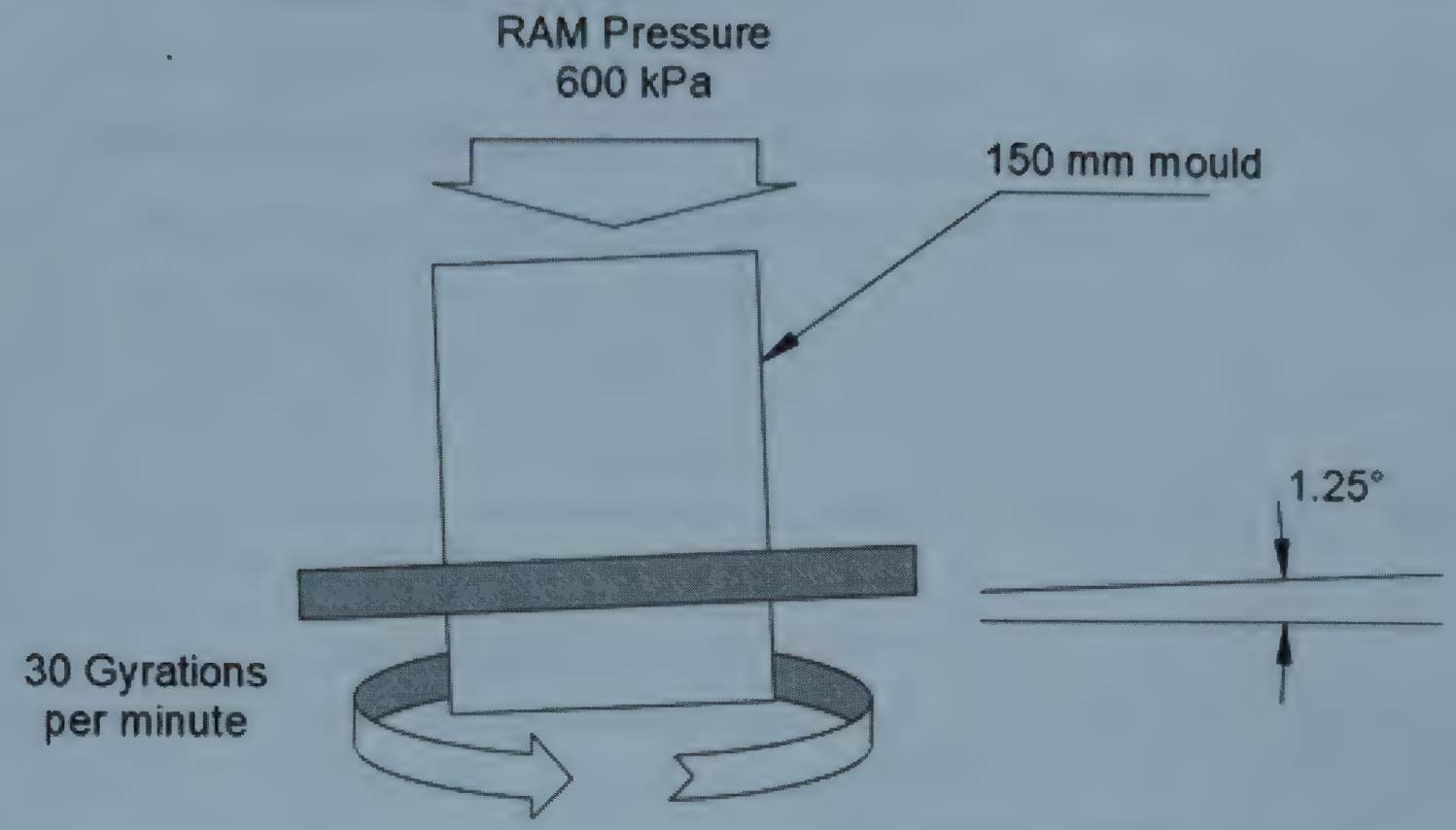


Fig. 9.1 Schematic Representation of Superpave Gyratory Compactor Effort

AASHTO R 35 establishes specified level of laboratory compaction (density) for three degrees of gyration based on expected traffic loading. **Fig. 9.2**, shows the density of the bituminous mix increases with increasing gyrations. There are three critical points on the SGC curve, the $N_{initial}$, N_{design} and $N_{maximum}$, shown in **Fig. 9.2**. $N_{initial}$ is to check for tenderness of the mix and the mix should not compact too quickly at N_{ini}. N_{design} is the design number of gyrations and the volumetric properties are checked at N_{des}. $N_{maximum}$ is the maximum number of gyrations to prevent rutting in bituminous mixes during the secondary compaction (N_{max}). **Table 9.1** shows the range of values for N_{ini}, N_{des} and N_{max}.

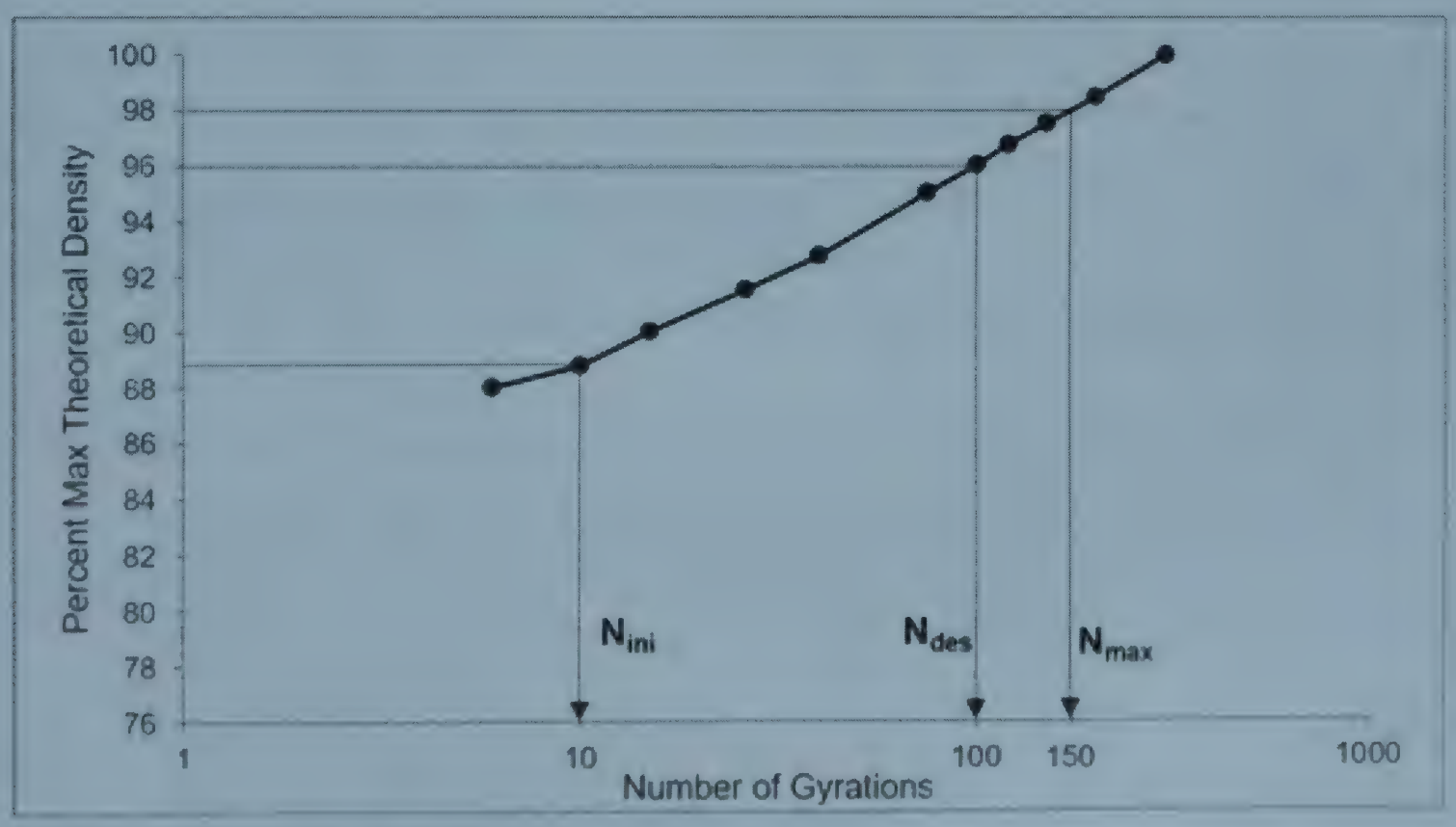


Fig. 9.2 Densification Curve (SHRP-A-407)

Table 9.1 Superpave Gyratory Compaction Effort

20-Year Design ESALs* (in millions)	Compaction Parameters			Typical Roadway Applications
	$N_{initial}$	N_{design}	$N_{maximum}$	
3 to <30	8	100	160	Applications include many dual lanes, multi-lanes, shared, and partially or fully controlled highways. These include medium to high-traffic city streets, District Roads, and some regional highways.
≥30	9	125	205	The application includes most of the National highway system. Special applications such as truck weighing stations and dual roadway truck climbing trucks can also be used at this level.
*Laboratory compaction parameters should be based on 20-year design traffic, regardless of the pavement design life of the roadway.				

9.2 Superpave Materials Selection

A mix will perform successfully if the appropriate binder and aggregate materials are used for the mix design.

9.2.1 *Bitumen Selection*

Bitumen is selected based on the climate and traffic they will be serving. These binders are classified according to their physical properties and their performance. If modified binders are used for Superpave mix design, the binder testing should be carried out as per IS: 15462-2019, and IS:17079-2019.

9.2.2 *Aggregate Selection*

Pavement experts agreed that certain aggregate qualities were required for designing a well-performing bituminous mix. The tests on aggregate are given in Chapter 4. The aggregate properties fulfilling the requirements given in chapter 4 is sufficient for designing the Superpave mixes. The gradation specified by the IRC (Chapter 5) can be used for the design of Superpave mix. **Fig. 9.3** shows the 0.45 power gradation chart showing the Superpave gradation control points. The selected gradation must pass through these control points.

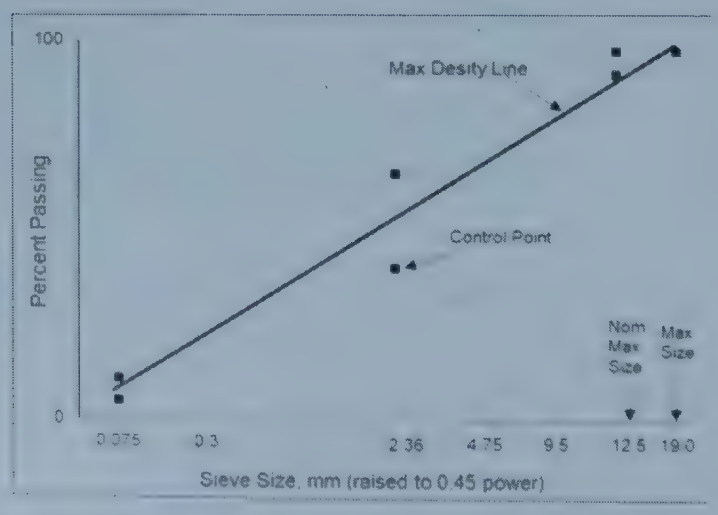


Fig. 9.3 Superpave Gradation showing Control Points

9.3 Specimen Preparation and Compaction

9.3.1 *Number of Specimens Required*

The following specimens must be prepared to conduct a Superpave mix design:

- Mixtures compacted to N_{des} requires a minimum of 8 specimens
- N_{max} verification requires a minimum of two specimens
- Maximum theoretical specific gravity (G_{mm}) testing requires a minimum of 2 specimens
- Moisture sensitivity testing requires a minimum of 6 specimens, according to AASHTO T 283
- any other samples required for specified performance testing

Three aggregate sample sizes are used for Superpave mix design, depending on their final use. The specimen size for compacted G_{mb} samples is 150 mm in diameter by 115 mm in height, with two samples roughly 4,700 gm of aggregate for each trial bitumen content, plus two additional specimens for N_{max} verification testing.

At least two samples must prepared in order to determine the maximum theoretical specific gravity (G_{mm}). These samples are uncompacted and range in size from 1,000 to 2,500 gm, depending on the Nominal Maximum Aggregate Size (NMAS) of the mixture, as specified in AASHTO T 209/ASTM D2401. The bitumen binder content of these samples will be equal to or more than the final estimated design binder content. A minimum of 6 specimens with a height of 95 mm are required for moisture damage testing using AASHTO T 283. Approximately 3,700 gm of aggregate are required for these samples.

9.3.2 *Preparation of Mixtures*

- Set the balance to zero and place the hot mixing bowl on it.
- Pour the heated aggregates into the mixing bowl and thoroughly mix.
- Form a crater in the blended aggregate and weigh the required bitumen in the mixture to obtain desired batch weight.
- Remove the mixing bowl from the scale and use a mechanical mixer to mix the bitumen and aggregate.
- Mix the specimen for 30–90 seconds, or until the aggregate is completely coated.
- Spread the mixture evenly in a shallow flat pan with a depth of 25 to 50 mm.
- Place the mix and pan in the conditioning oven at a temperature equal to mixture's specified compaction temperature ± 3°C.
- Repeat this process until the desired number of specimens are produced.
- Allow about 20 minutes between mixing each specimen to ensure proper gyratory compaction timing.

- If the mixture is to be used to determine maximum theoretical specific gravity, proceed to AASHTO T 209/ASTM D2041 at the end of the short-term aging period. Otherwise, proceed compaction.

9.3.3 *Volumetric Parameters*

After the data has been plotted, the field engineers will select an optimum bitumen content that will provide 4% air voids at N_{des}. Then the field engineers determine the air voids, VMA, VFB.

9.4 Moisture Sensitivity Test

The moistures sensitivity of the designed bituminous mix should be tested as given in Chapter 6.

Note: *SUPERPAVE method generally, results in lower optimum binder content which will be prone to cracking. Therefore, the bitumen film thickness at optimum binder content should be in the range of 6 to 8 µm. If the film thickness is less, the binder content should be increased to have a minimum film thickness in the range of 6 to 8 µm. Higher bitumen content in a dense mix, leads to an unstable mix.*

BIBLIOGRAPHY

AASHTO. 2014c. Standard method of test for resistance of compacted asphalt mixtures to moisture-induced damage. AASHTO T 283. Washington, DC: AASHTO.

Asphalt Institute. (1996). Superpave mix design (No. 2). Asphalt Institute.

ASTM, A., (2015). D6927–15 Standard test method for Marshall stability and flow of asphalt mixtures. West Conshohocken, PA, USA: ASTM International.

BIS (Bureau of Indian Standards). 1978a. Methods for testing tar and bituminous materials: Determination of penetration. IS 1203-1978. New Delhi, India:

BIS (Bureau of Indian Standards). 1997. Methods of test for aggregates for concrete. IS 2386 (Part 1-5). New Delhi, India: BIS.

BIS (Bureau of Indian Standards). 2013. Paving bitumen. IS 73-2013. New Delhi, India: BIS.

BIS (Bureau of Indian Standards). 1978b. Methods for testing tar and bituminous materials: Determination of softening point. IS 1205-1978. New Delhi, India:

BIS (Bureau of Indian Standards). 1978c. Methods for testing tar and bituminous materials: Determination of specific gravity. IS 1202-1978. New Delhi, India: BIS.

Brown, E. R., Lord, B., Decker, D., and Newcomb, D. (2000). Hot mix asphalt tender zone (No. NCAT Report No. 2000-02). National Center for Asphalt Technology.

https://iowadot.gov/training/ttcp/training_manuals/HMAFieldInspectionManual.pdf

IRC:111-2009 “Specification for Dense Graded Bituminous Mixes”, Indian Road Congress

IRC:37-2018 “Guidelines for the Design of Flexible Pavements”, Indian Roads Congress.

Katla, B., Raju, S., Waim, A. R., & Danam, V. A. (2021). Utilization of Higher Percentages of RAP for Improved Mixture Performance by Adopting the Process of Fractionation. International Journal of Pavement Research and Technology, 1-18.

Ministry of Road Transport and Highways, (2013) “Specifications for Road and Bridges Works” Fifth Revision, New Delhi.

MS-4 (2007) “The Asphalt Handbook”

Nivitha, M.R. and Krishnan, J.M., 2014. Development of pavement temperature contours for India. Journal of The Institution of Engineers (India): Series A, 95(2), pp.83-90.

Radhakrishnan, V., (2018), Evaluation of Rutting Potential of Bituminous Mixes, PhD thesis, unpublished, IIT Kharagpur.

Radhakrishnan, V., Chowdari, G. S., Reddy, K. S., & Chattaraj, R. (2019). Evaluation of wheel tracking and field rutting susceptibility of dense bituminous mixes. Road Materials and Pavement Design, 20(1), 90-109

S Bose, Sridhar. R, C Kamaraj and Meena R K, (2003) "Performance-Based Mix Design Using Superpave Gyratory Compactor", Journal of the Indian Roads Congress, Volume 64, No-2.

SHRP-A-407 The Superpave Mix Design Manual for New Construction and Overlays, (1994), Strategic Highway Research Program, USA.

Sridhar. R, Sunil Bose, Nilanjan Sarker and Girish Sharma, (2006) "Refusal Density Concept for Design of Dense Bituminous Mixes, Highway Research Bulletin, Indian Roads Congress, Vol 78, 2006.

Sridhar. R, Sunil Bose, Nilanjan Sarker and P.K. Nanda, (2007) "Influence of Refusal Density on Design of Bituminous Mixes", Indian Roads Congress, New Delhi.

The Asphalt Institute, "Mix Design Methods for Asphalt Concrete and Other Hot Mix Types MS-2" Seventh Edition.

Transportation Research Board (TRB). (2000). Hot-Mix Asphalt Paving Handbook 2000. Transportation Research Board, National Research Council. Washington, D.C.

TRL, 2002. A guide to the design of hot mix asphalt in tropical and sub-tropical countries. Overseas Road Note 19.

ANNEX I

STEPS FOR MARSHALL SPECIMEN PREPARATION

The bituminous mixture design procedure is conducted by preparing trial mixtures at five different binder content percentages. The percentage of initial binder content is determined using the computational formula is given in eq. 1 (Asphalt Institute MS-2).

$P = 0.035a + 0.045b + Kc + F$ ..... *Eq 1*

Where,

P = approximate bitumen content of mix, percent by weight of mix

a = percent of mineral aggregate retained on 2.36 mm sieve

b = percent of mineral aggregate passing the 2.36 mm sieve and retained on the 75 µm sieve

c = percent of mineral aggregate passing 75 µm sieve

K = 0.15 for 11–15 percent passing 75 µm sieve

0.18 for 6–10 percent passing 75 µm sieve

0.20 for 5 percent or less passing 75 µm sieve

F = 0 – 2.0 and it is based on the absorption of light or heavy aggregate. In the absence of data, a value of 0.7 may be considered.

Mixing and compaction temperature

The mixing temperature is at the binder viscosity of 0.17±0.02 Pa.s and

The compaction temperature is at the binder viscosity of 0.28±0.03 Pa.s.

Preparation of Test Specimens

As per the Job mix formula, the aggregate and filler material are selected to fulfil the design requirements of the specified gradation. Approximately 1150 g of aggregate for 100 mm diameter specimens (4050 g aggregate for 150 mm diameter specimens) as per the gradation are placed at 170 °C to 180 °C in an oven for 4 hours. The binder is heated to about 160 and 180 °C (based on the type and grade of bitumen) in an oven for 2 hours. The compaction mould is also placed in the oven at 100 °C to 150 °C. The preheated bitumen and the preheated aggregates are mixed thoroughly at the specified temperature preferably using a mechanical mixer. After mixing, the mix is placed in the oven at 140 to 150 °C for 2 hours to simulate the short term ageing. After, the short term ageing, the mix is transferred to the preheated mould and compacted by applying 75 blows on each face for 100 mm diameter specimens (112 blows on each face for 150 mm

diameter specimens). A total of three specimens should be prepared at each binder content and the Marshall specimens should be prepared for 5 different binder contents, the initial binder content, initial binder content ±0.5%, and initial binder content ±1%.

Determination of Bulk and Theoretical/Maximum Specific Gravity

The compacted test specimens are cooled to room temperature and demoulded. The thickness and diameter of the demoulded specimen should be measured. To determine the volumetric parameters of the mixes, the bulk specific gravity (G_{sb}) and maximum specific gravity (G_{mm}) of the mixtures should be measured.

Determination of Marshall Stability and Flow Values

The demoulded specimens are placed in a water bath at 60 ± 1 ^{o}C for 30 to 40 mins before testing. The specimen is then transferred to Marshall test head for testing the stability. The load is applied at a constant deformation rate of 50.8 mm/min (2"/min). The maximum load reading and corresponding deformation are noted which are the Marshall Stability and flow values, respectively. A correction factor is applied to the Marshall stability value based on the specimen dimensions as shown in **Table A-I-1** for 100 mm diameter specimens and given in **Table A-I-2** for 150 mm diameter specimens.

Table A-I-1 Stability Correction Factor for 100 mm Diameter Specimens

Volume of Specimen, cm^3	Approximate Thickness of Specimen, mm	Correlation Ratio
471 to 482	58.7	1.14
483 to 495	60.3	1.09
496 to 508	61.9	1.04
509 to 522	63.5	1.00
523 to 535	65.1	0.96
536 to 546	66.7	0.93
547 to 559	68.3	0.89

Table A-I-2 Stability Correction Factor for 150 mm Diameter Specimens

Volume of Specimen, cm^3	Approximate Thickness of Specimen, mm	Correlation Ratio
1637 to 1665	90.5	1.09
1666 to 1694	92.1	1.06
1695 to 1723	93.7	1.03
1724 to 1752	95.2	1.00
1753 to 1781	96.8	0.97
1782 to 1810	98.4	0.95
1811 to 1839	100	0.92

Performance Tests on the Marshall Specimens

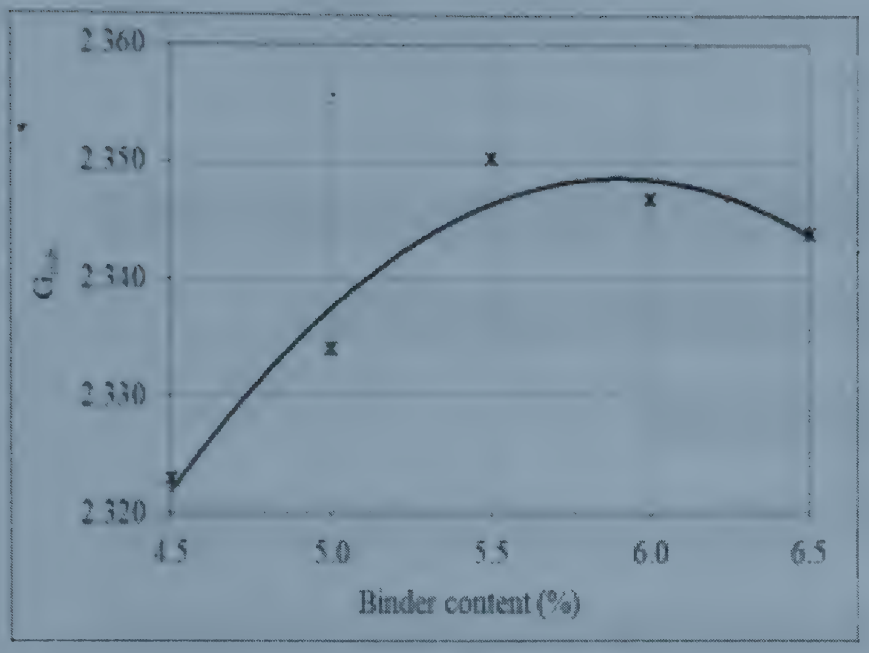
I. The moisture sensitivity tests should be carried out for mixes considered for design traffic of <10 msa as given in section 6.3.4.

II. The moisture sensitivity tests, the rutting tests as given in section 6.3.7, and fatigue tests as mentioned in section 6.3.8 should be done for the mixes considered for a design traffic of ≥10<50 msa.

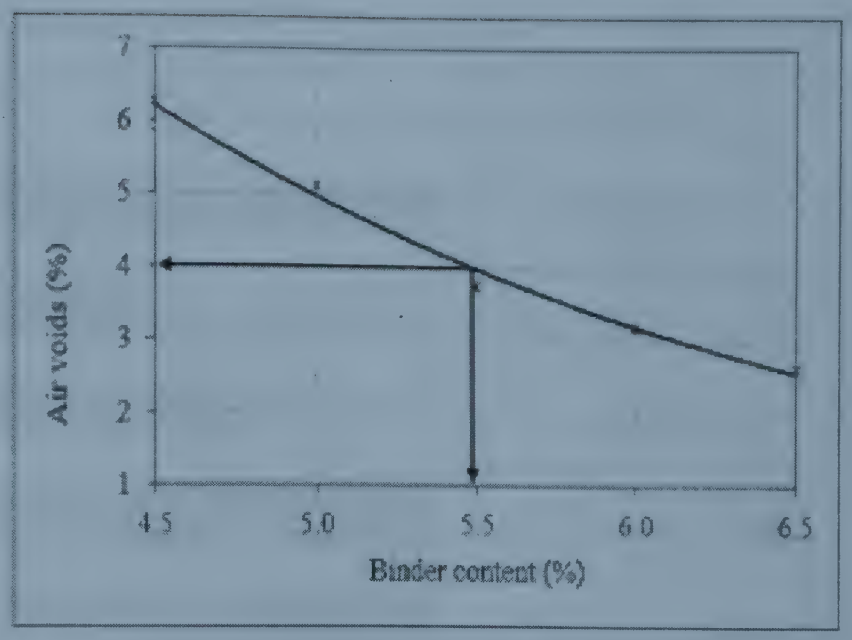
III. The moisture sensitivity tests, the rutting tests, the fatigue tests, and also the mixes should be designed for refusal density as mentioned in section 8.1, if the design traffic of ≥50 msa.

Table A-II-1 Volumetric Properties BC Mix with 13.2 NMAS

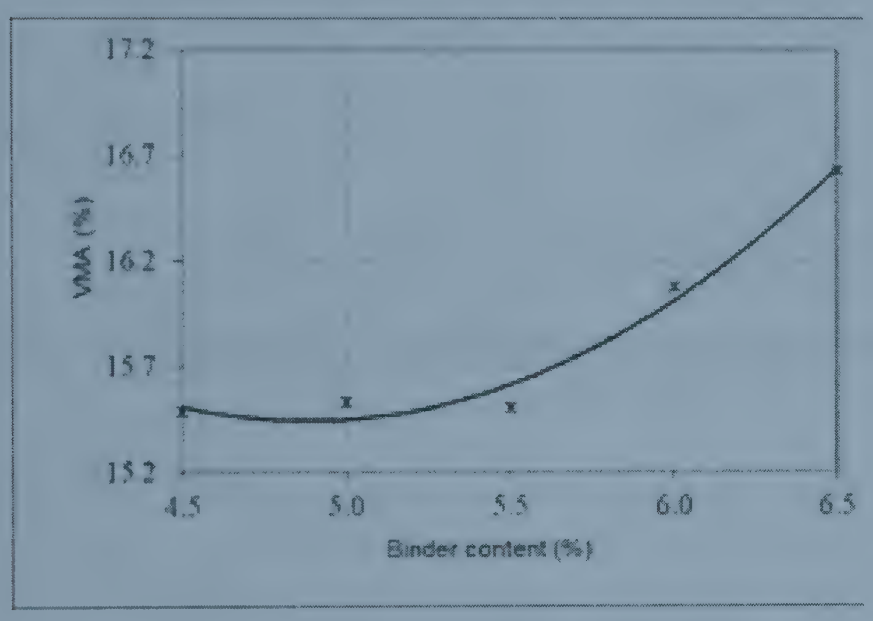
Specific gravity of the Bitumen (G_b) = 1.03 Bulk Sp.gr of aggregate (G_{sb}): X=2.625				Effective sp.gr of aggregate (G_{se}): =2.647 Apparent sp.gr of aggregate (G_{sa}): =2.662				Grade of bitumen =VG30					
Binder content by total mixture weight (%)	**Sample no**	**Weight of the aggregate by total mixture weight (%)**	**Thickness of the specimen (mm)**	**Dry Weight (g)**	**Submerged Weight (g)**	**Saturated Weight (SSD) (g)**	**Bulk specific gravity of the mixture (G_{mb}) (g/cc) (E/(G-F))**	**G_{mm}**	**Air voids (%) (I-H)/I *100**	**VMA (%) 100-((I*C)/X)**	**VFB (%) (K-J)/K*100**	**Stability (kN)**	**Flow (mm)**
A	B	C	D	E	F	G	H	I	J	K	L	N	P
4.5	1	95.5	61.5	1134	649	1137	2.324	2.478	6.3	15.489	59.6	11.8	2.3
	2	95.5		1143	655	1147	2.323					12.5	2.3
	3	95.5		1154	658	1155	2.322					12.6	2.9
	Average						**2.323**					**12.3**	**2.5**
5.0	1	95.0	61.2	1147	659	1150	2.336	2.460	5.1	15.531	67.0	12.1	3.2
	2	95.0		1157	664	1160	2.333					13.2	3.2
	3	95.0		1134	652	1138	2.333					13.6	2.1
	Average						**2.334**					**13.0**	**2.9**
5.5	1	94.5	60.7	1141	658	1144	2.348	2.442	4.0	15.505	74.8	13.8	2.8
	2	94.5		1169	676	1172	2.357					14.1	3.4
	3	94.5		1159	668	1162	2.346					14.3	3.1
	Average						**2.347**					**14.1**	**3.1**
6.0	1	94.0	61.3	1162	670	1165	2.347	2.425	3.3	16.077	79.2	12.2	4.4
	2	94.0		1173	675	1176	2.341					12.5	4.2
	3	94.0		1171	673	1173	2.342					11.7	4.5
	Average						**2.344**					**12.1**	**4.4**
6.5	1	93.5	62.3	1163	670	1167	2.340	2.407	2.7	16.627	83.4	11.3	4.5
	2	93.5		1171	673	1173	2.342					11.1	4.6
	3	93.5		1163	666	1163	2.340					10.7	4.5
	Average						**2.341**					**11.0**	**4.5**



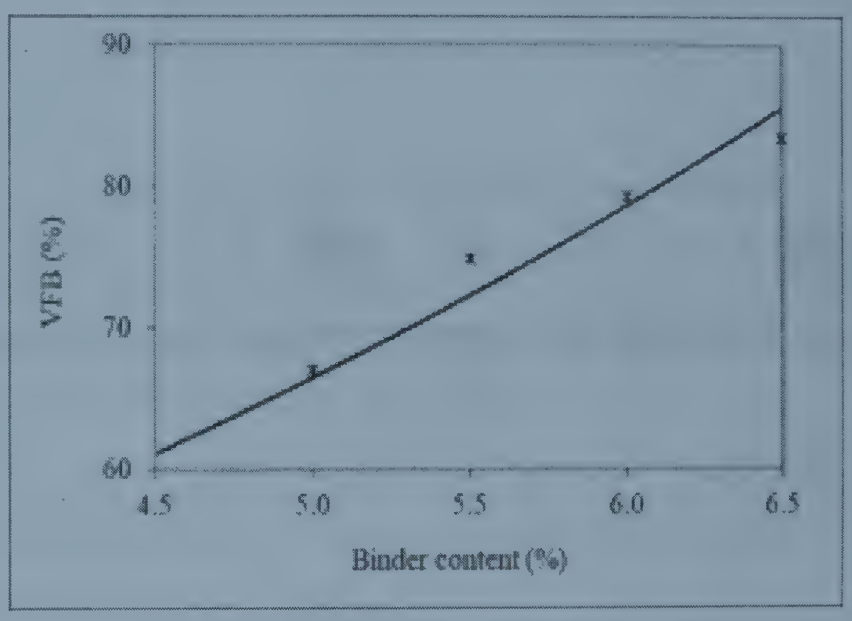
a) Bulk Density



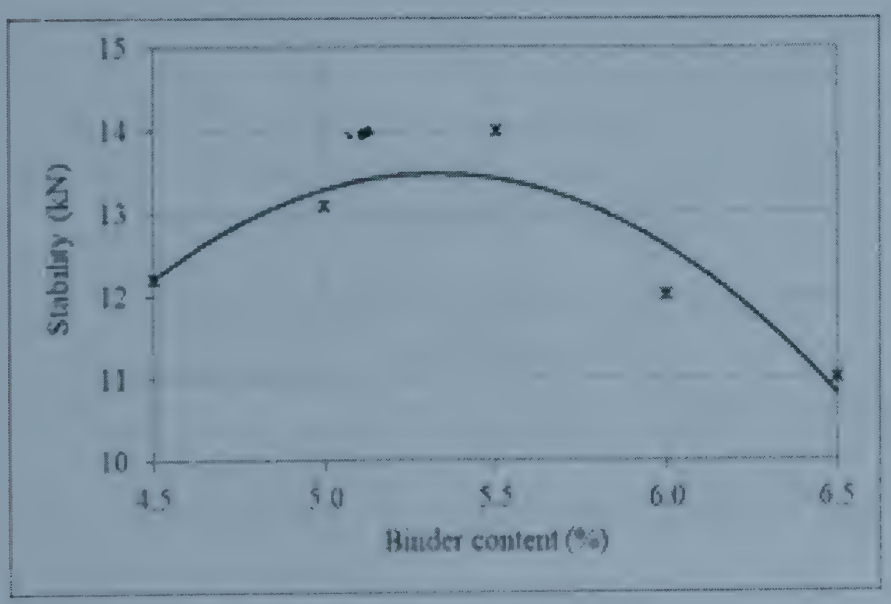
b) Air Voids



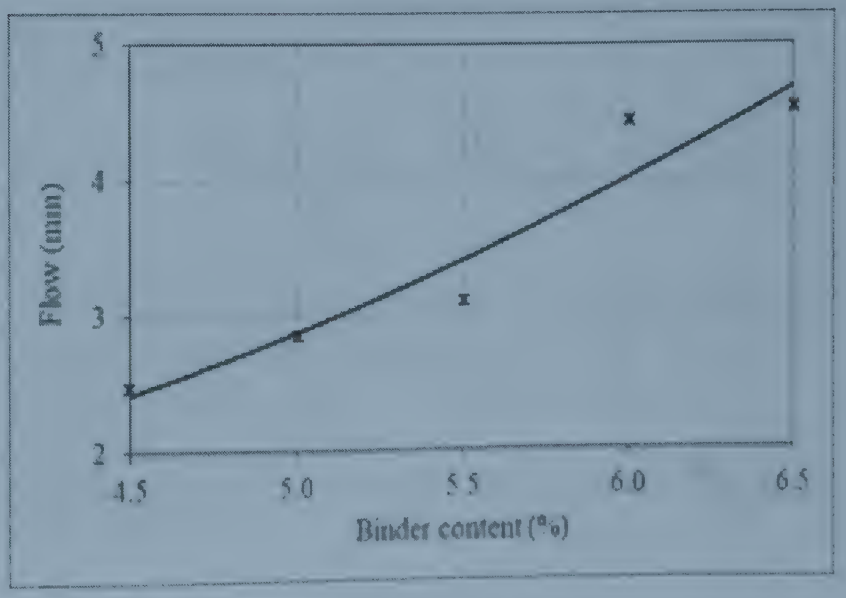
c) Voids in Mineral Aggregates



d) Voids filled with Bitumen



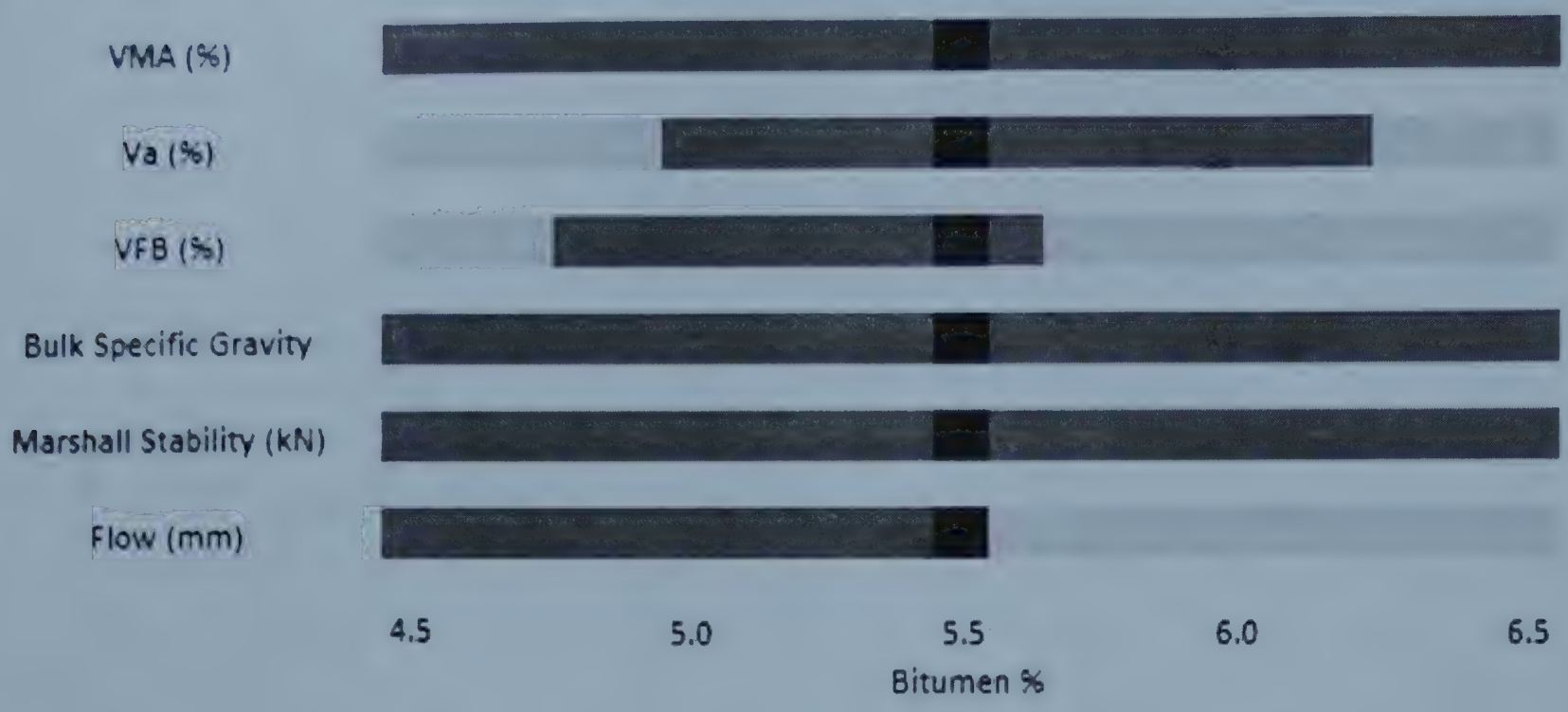
e) Marshall Stability



f) Flow Value

Fig. A-II-1 Graphical Representation of BC with NMAS 13.2 mm

At the optimum binder content, Marshall samples have to be prepared to verify the volumetric, and strength parameters with the MoRT&H Specifications.



Fulfils the Criteria **Meets all the criteria including 4% air void content**

Fig. A-II-2 Mix Volumetric Properties and Strength Parameters at different Binder Contents

ANNEX III

SOXHLET EXTRACTION

This test method sets out the procedure to find the bitumen content from a bituminous mixture using a Soxhlet extraction apparatus.

Procedure:

1. Prepare a pouch with the filter paper, and take the weight of the pouch to the nearest 0.01 g (**A**).
2. Take a 1000 g of the bituminous mixture and keep it in the oven at 100°C for 30 min. After heating, pulverize the bituminous mixture and transfer the pulverized mixture in to the pouch. Weigh the pouch with mixture to the nearest 0.01 g (**B**).
3. Place the pouch directly into the Soxhlet extractor.
4. Fill the round bottomed flask about half full of solvent and place it on the heating mantel.
5. Place the Soxhlet extractor on top of the round bottom flask as shown in the **Fig A-III-1**. Fix the condenser on top of the Soxhlet extractor and place cotton (loosely) at the open end, but ensure that there is a continuous flow of cool water through the condenser.
6. Set the temperature in the heating mantel just enough to vaporize the solvent. Condense the vaporized solvent in the condenser so that the solvent falls in to the Soxhlet extractor. Condensed solvent dissolves the bitumen in the mixture.
7. Continue the extraction process till the solvent become colourless in the Soxhlet extractor.
8. Allow the Soxhlet extractor to cool. Remove the pouch from the Soxhlet extractor, keep it in an oven at 80 to 90°C until complete removal of the solvent.
9. After drying, allow the pouch to cool down to room temperature. Take the weight of the pouch with aggregate sample (**C**).
10. Filter the solvent in the round bottom flask with a filter paper (take a filter paper weight before filtering, **D**). After filtering, dry the filter paper and take the weight of the filter paper along with some fines which might have escaped during extraction process (**E**).
11. Use the extracted aggregate weight, and the fine aggregate that was stuck to the filter paper [(C+E)-(B+D)].
12. The bitumen content in the mixture shall be determine as

$$Bitumen\ content\ (\%) = \frac{B-[(C+E)-(A+D)]}{B} \times 100$$

A – Weight of pouch

B – Weight of sample

C – Weight of sample with pouch after extraction

D – Weight of filter paper

E – Weight of fine particle with filter paper

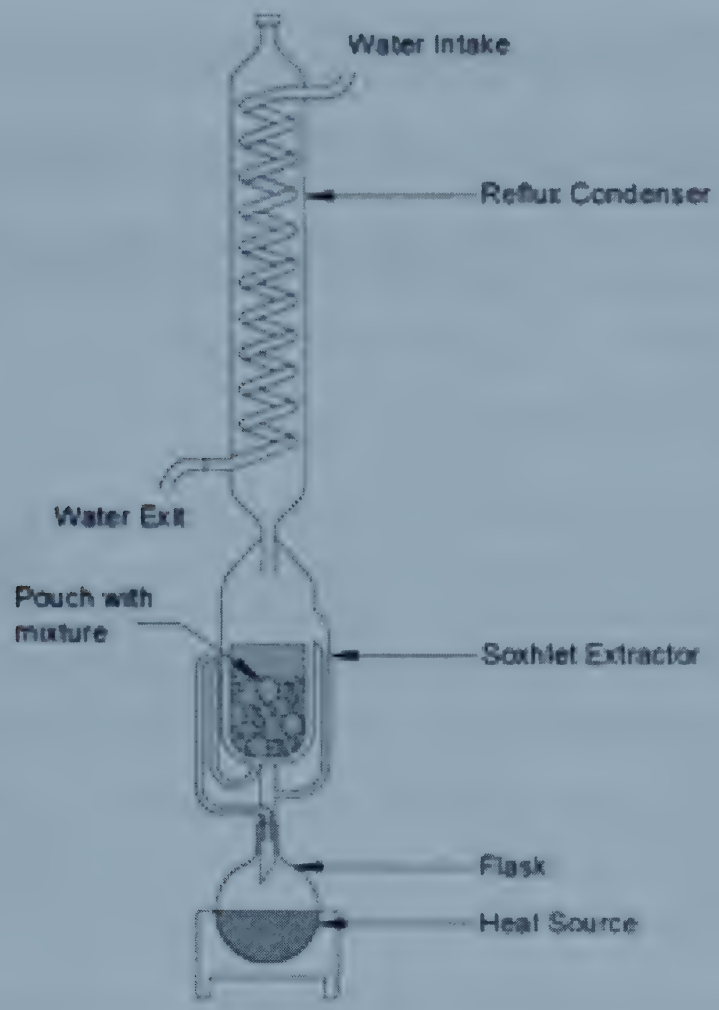


Fig. A-III-1 Soxhlet Apparatus

ANNEX IV

MIX DESIGN EXAMPLE – 30% RAP

Design of 30% RAP added bituminous mixes is given below. In the example, the bitumen content of RAP material,(P_{bRAP}) was calculated and found to be 4%.

i. For determining the combined aggregate gradation, 30% RAP was considered, but the RAP material also, consists of (4*0.3 = 1.2% bitumen). Therefore, RAP aggregate will be 30-1.2 = 28.8%.

ii. The percentage of virgin aggregate (by weight of aggregate), consisting of 20 mm, 10 mm, 6 mm, and stone dust, were 15, 25, 10, and 50%, respectively. After adding 30% RAP material (28.8% RAP aggregate by weight of aggregate), the proportioning of aggregate consisting of 20 mm, 10 mm, 6 mm, stone dust, and RAP aggregate, were 10.7, 17.8, 7.1, 35.6, and 28.8, respectively.

iii. Therefore, 1,100 g of aggregate consists of 117.7 g (20 mm), 195.8 g (10 mm), 78.1 g (6 mm), 391.6 g (stone dust), and 316.8 g (RAP aggregate).

iv. The quantity of virgin binder should be calculated assuming the total binder as 5% at OBC. Therefore, the weight of virgin bitumen can be calculated as given below:

$$\textit{Extra virgin binder weight} = 1100 \times \frac{5^*}{95} - (300 - 316.8) = 44.7 \text{ grams}$$

v. The quantity of virgin binder is calculated for a mix with 5% total binder content. Therefore, the weight of virgin binder is 44.7 g, and the weight of RAP binder is 13.2 g, and the total binder is 57.9 g.

vi. Determine the bulk specific gravity, and the maximum specific gravity of RAP material.

$$G_{mm\,(RAP)} = \frac{A - J}{(A + D) - (E + K)}$$

$$G_{mm\,(RAP)} = \frac{1537 - 30}{(1537 + 12646) - (13576 + 29.411)} = 2.609$$

$$G_{se(RAP)} = \frac{100 - P_{b(RAP)}}{\frac{100}{G_{mm(RAP)}} - \frac{P_{b(RAP)}}{G_{b(RAP)}}} = \frac{100 - 4}{\frac{100}{2.609} - \frac{4}{1.04}} = 2.784$$

$$G_{sb(RAP)} = \frac{G_{se(RAP)}}{\frac{P_{ba(RAP)} \times G_{se(RAP)}}{100 \times G_{b(RAP)}} + 1} = \frac{2.784}{\frac{0.4^a * 2.784}{100 \times 1.04} + 1} = 2.754$$

[a]Binder absorption (P_{ba}) for RAP aggregate is assumed to be 0.4%.

Where,

A – weight of RAP sample

D – weight of container filled with water

E – weight of the container filled with the sample and water

J – weight of extra binder added to RAP material

K – volume of the extra binder, cc $= \frac{J}{G_b}$

G_b – specific gravity of the extra binder added

$G_{sb\ (RAP)}$ – bulk specific gravity of RAP aggregate

$G_{se\ (RAP)}$ – effective specific gravity of RAP aggregate

Properties of RAP Material

G_{mm} of RAP	2.609
RAP binder content (P_b)	4.0 %
Binder absorption(P_{ba}) of RAP aggregate is	0.4%
Therefore, effective RAP binder is	3.6%
Specific gravity of the RAP binder G_b (RAP)	1.04
Effective specific gravity of RAP agg. [$G_{se\ (RAP)}$]	2.784
Bulk specific gravity of the RAP agg. [$G_{sb\ (RAP)}$]	2.754

Bulk Specific Gravity and Effective Specific Gravity of Virgin Aggregate

20 mm aggregate	2.625
10 mm aggregate	2.629
6 mm aggregate	2.590
Stone Dust	2.628

Effective Specific Gravity (G_{se}) of Virgin Aggregate

The maximum specific gravity, G_{mm} of conventional mix without RAP is 2.455 at 5.0% binder content, and the specific gravity of the virgin binder G_b – 1.02

$$G_{se\ (virgin\ agg)} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} = \frac{100 - 5.0}{\frac{100}{2.455} - \frac{5.0}{1.02}} = 2.651$$

Determine the Bulk Specific Gravity of Combined Aggregates:

$$G_{sb} = \frac{(P_1 + P_2 + P_3 + P_4 + P_5)}{(\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \frac{P_4}{G_4} + \frac{P_5}{G_5})}$$

$$G_{sb\ combinded\ (RAP\ and\ virgin)} = \frac{10.7 + 17.8 + 7.1 + 35.6 + 28.8}{\frac{10.7}{2.625} + \frac{17.8}{2.629} + \frac{7.1}{2.590} + \frac{35.6}{2.628} + \frac{28.8}{2.755}} = 2.660$$

Determine the Effective Specific Gravity of Combined Aggregates:

$$G_{se\ combinded\ (RAP\ and\ virgin)} = \frac{71.2 + 28.8}{\frac{71.2}{2.651} + \frac{28.8}{2.784}} = 2.688$$

Maximum Specific Gravity of Mix (G_{mm}) with 30% RAP

Determine maximum specific gravity of mix with 30% RAP

$$G_{mm\ (RAP)} = \frac{100}{\frac{P_{agg}}{G_{se}} + \frac{P_b}{G_b} + \frac{P_{b\ (RAP)}}{G_{b\ (RAP)}}}$$

$$\text{RAP binder (\%)} = \frac{13.2}{1157.9} \times 100 = 1{,}14\%$$

$$\text{Virgin binder (\%)(Extra binder)} = \frac{44.7}{1164} \times 100 = 3.84\%$$

$$G_{mm\ (30\%\ RAP)} = \frac{100}{(\frac{95}{2.688} + \frac{3.84}{1.02} + \frac{1.14}{1.04})} = 2.487$$

G_{mm} of bituminous mix with 30% RAP at 5.0 % binder content is 2.487

Similarly, the G_{mm} for other binder contents should be determined.

Volumetric Properties of Mix with 30% RAP

The other volumetric properties the bituminous mix with 30% RAP should be calculated as given in Chapter 6.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)

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